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Liu et al.

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(54) **UNLICENSED SPECTRUM COVERAGE
ENHANCEMENT FOR INDUSTRIAL
INTERNET OF THINGS**

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H04L 29/08 (2006.01)

(52) **U.S. Cl.**
CPC **H04L 29/0854** (2013.01); **H04L 29/08423** (2013.01); **H04L 29/08018** (2013.01); **H04L 29/08027** (2013.01)

(58) **Field of Classification Search**
CPC combination set(s) only.
See application file for complete search history.

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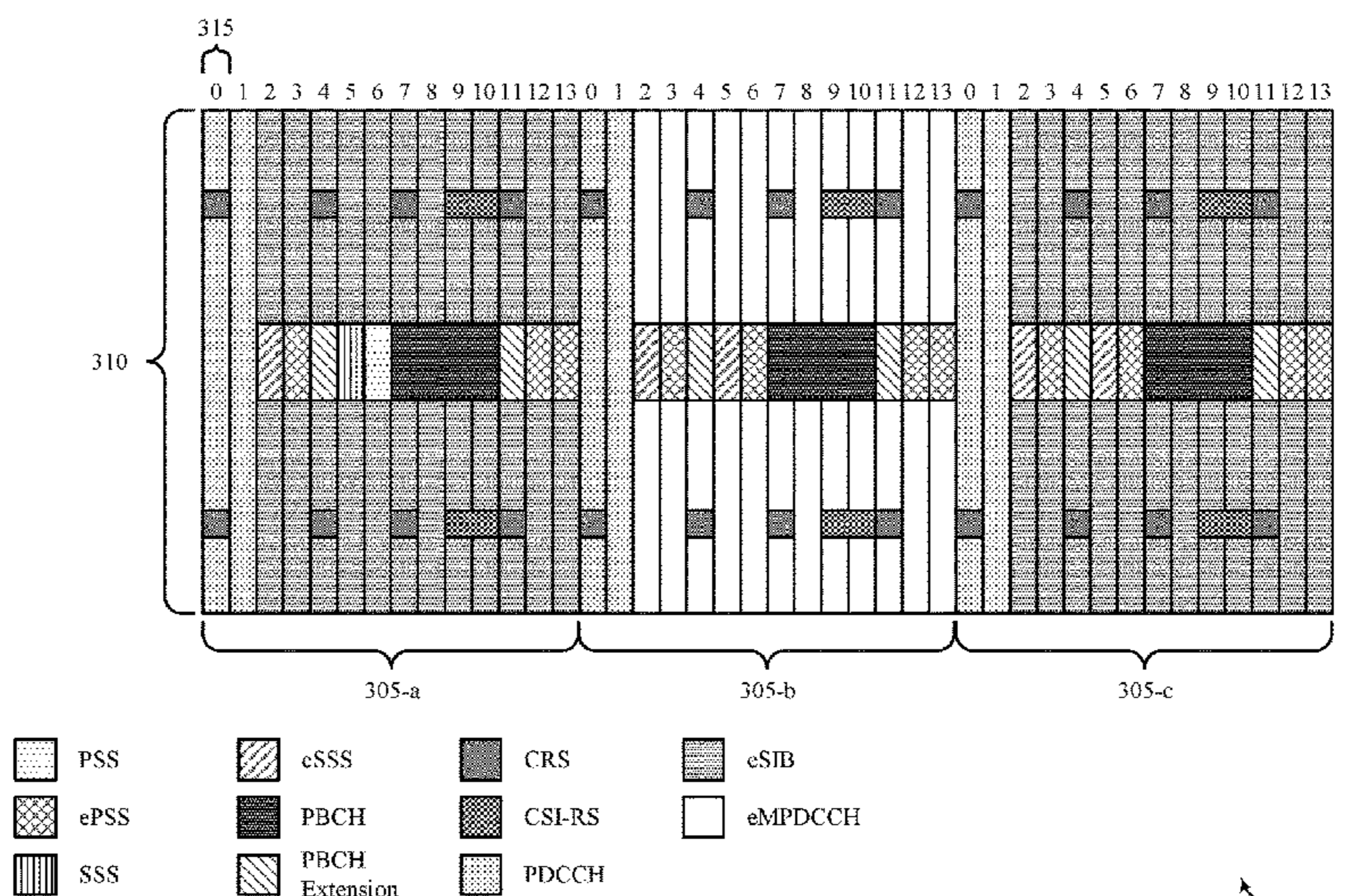
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(57) **ABSTRACT**

This disclosure includes methods, systems, and devices for wireless communication. A repetition of symbols may be used to increase a device's ability to synchronize and communicate using unlicensed spectrum. For example, a base station may schedule a frame that includes repetitions, in time or frequency, of a control or data signal. After performing a listen-before-talk (LBT) procedure, the base station may broadcast or transmit the frame to one or more devices, such as a user equipment (UE). For instance, the frame may include repetitions of a discovery reference signal (DRS), and be broadcast by the base station to enable synchronization by the UE. In other examples, the signal may include repetitions of a cell-specific reference signal (CRS), and a UE may identify a start of a transmission opportunity using the CRSs. Other signals, such as downlink control and shared channels, may be repeated within a frame in a similar manner.

26 Claims, 20 Drawing Sheets



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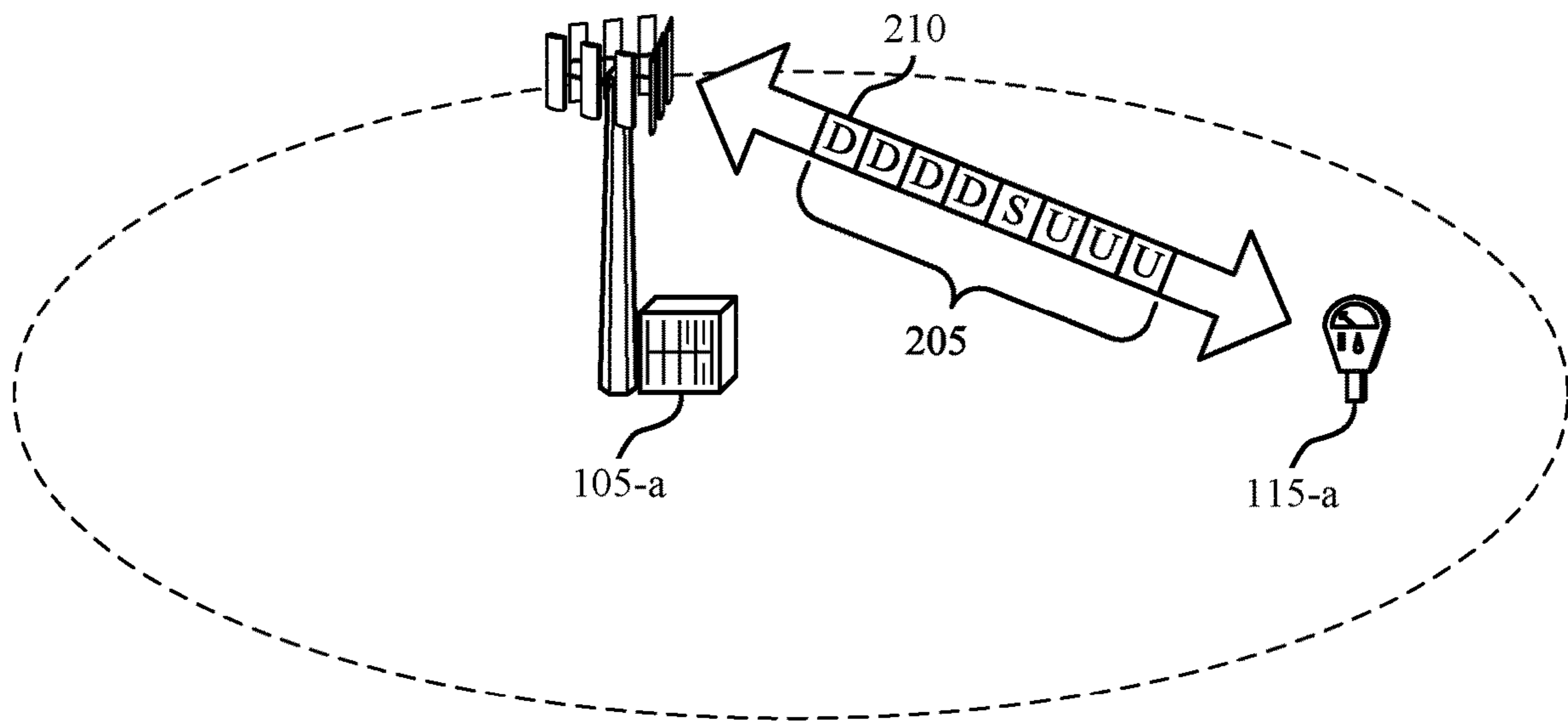


FIG. 2

200

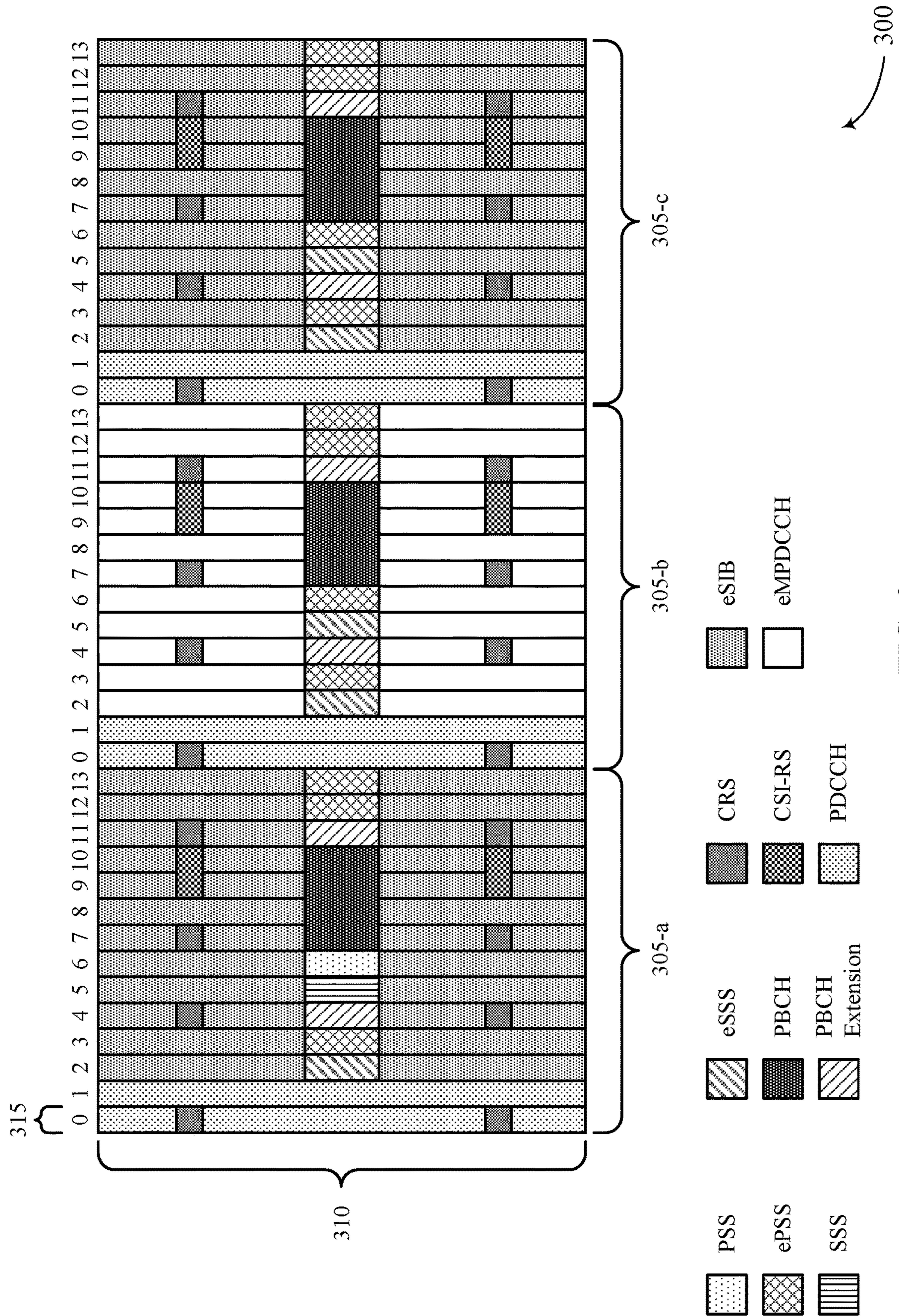
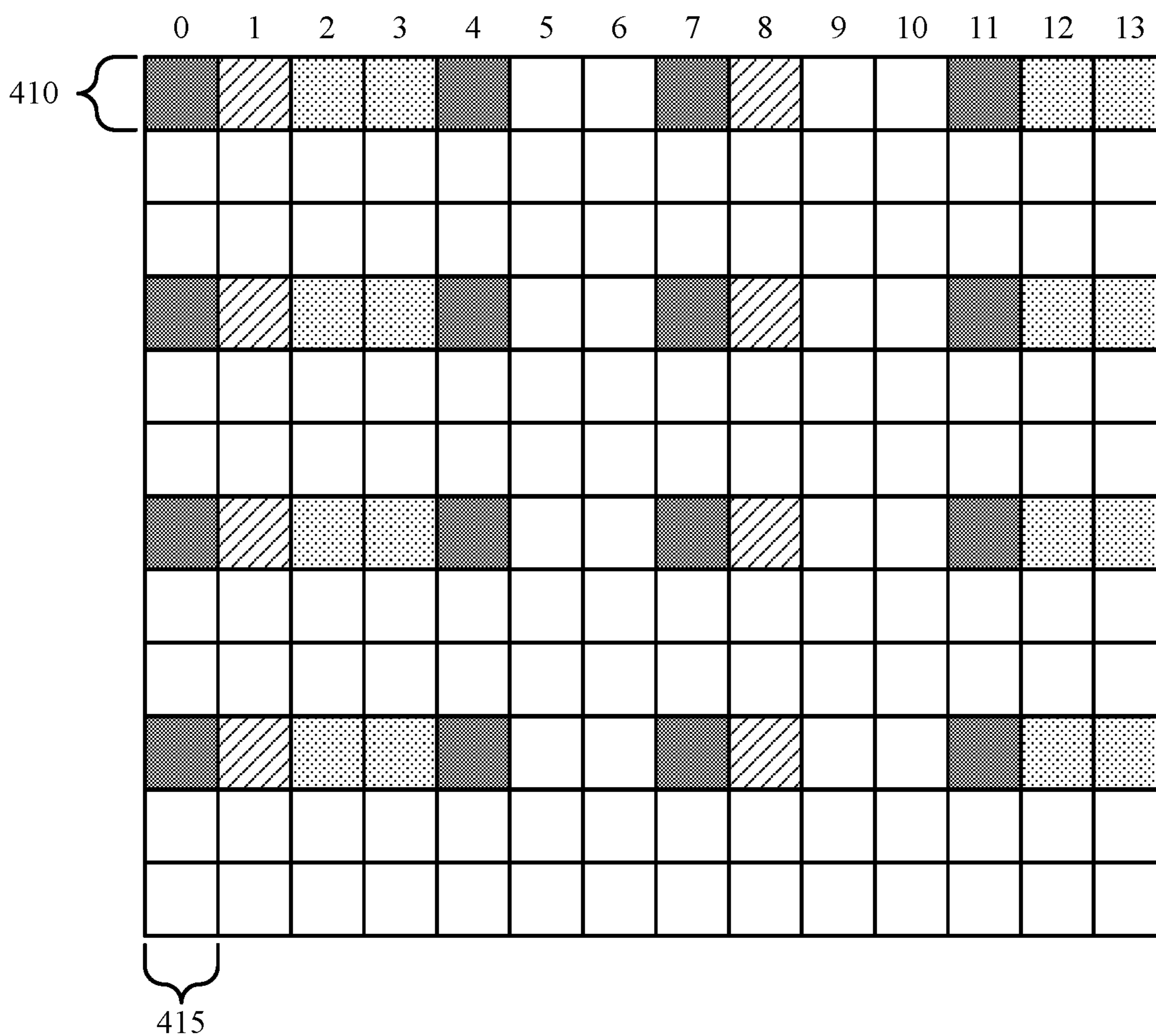


FIG. 3



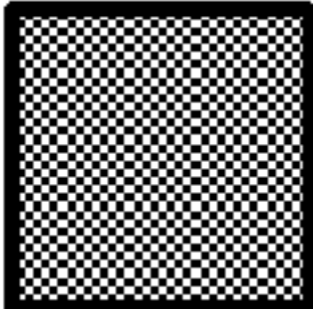
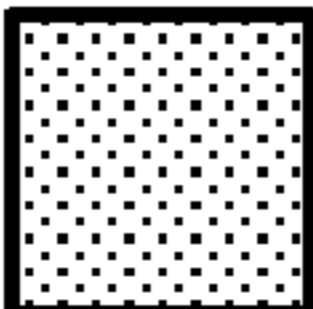

-  CRS AP 0/1 420
-  CRS Repetition AP 0/1 425
-  CRS AP 2/3 430

FIG. 4

400

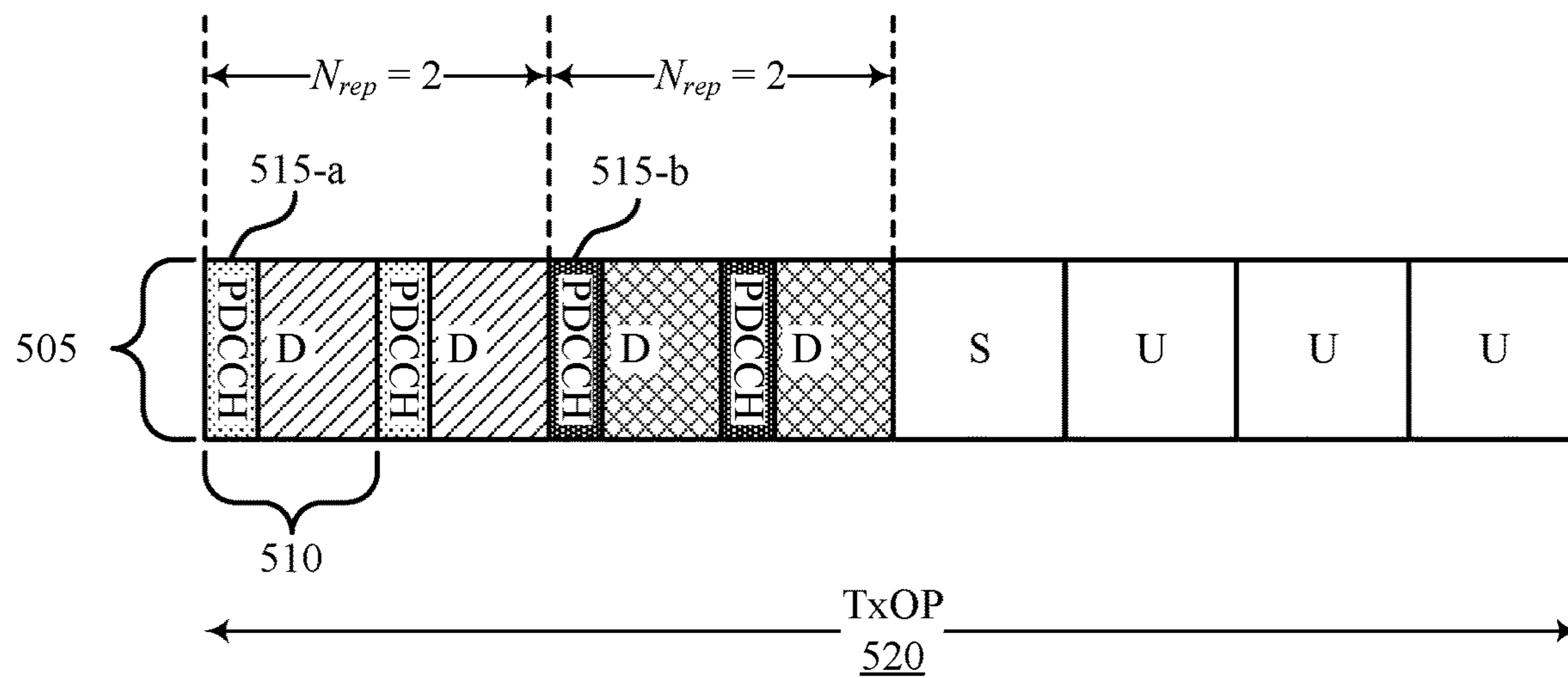


FIG. 5

500

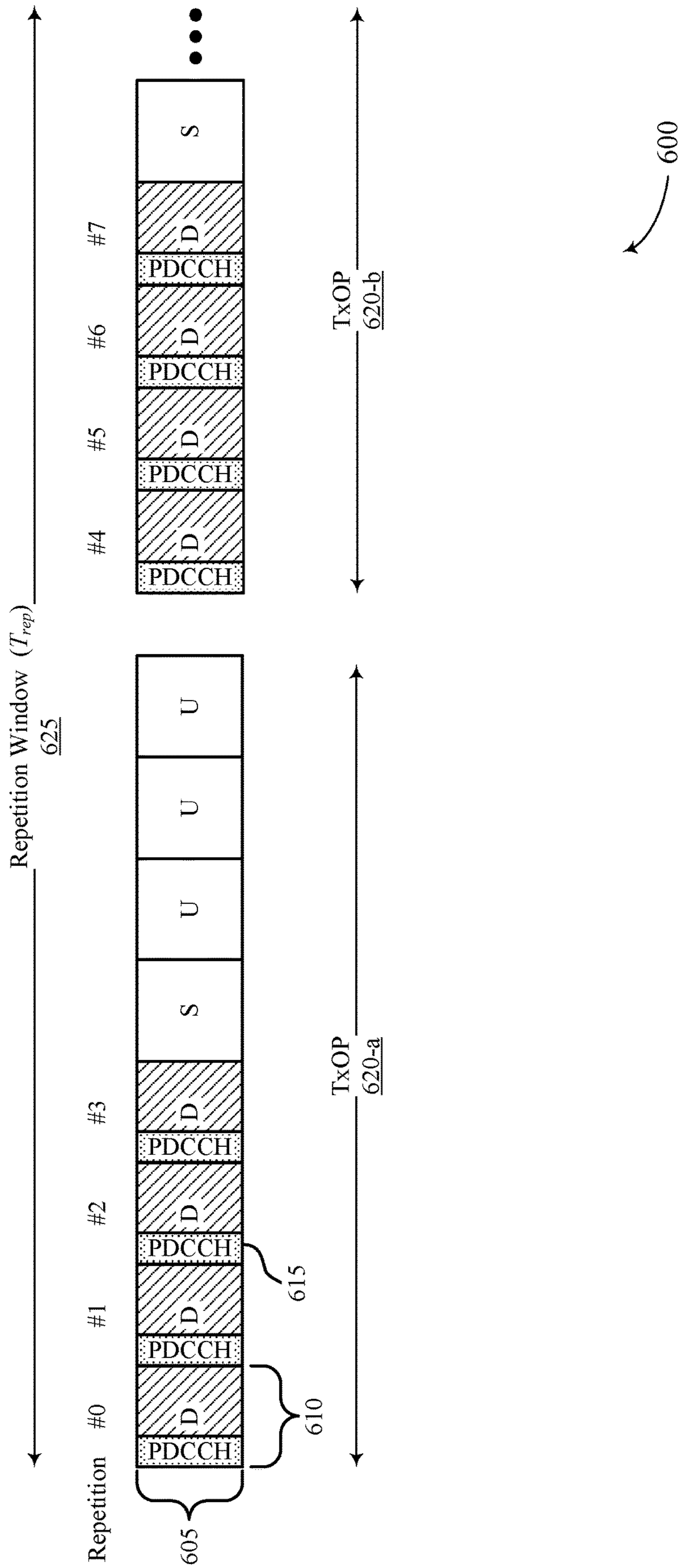


FIG. 6

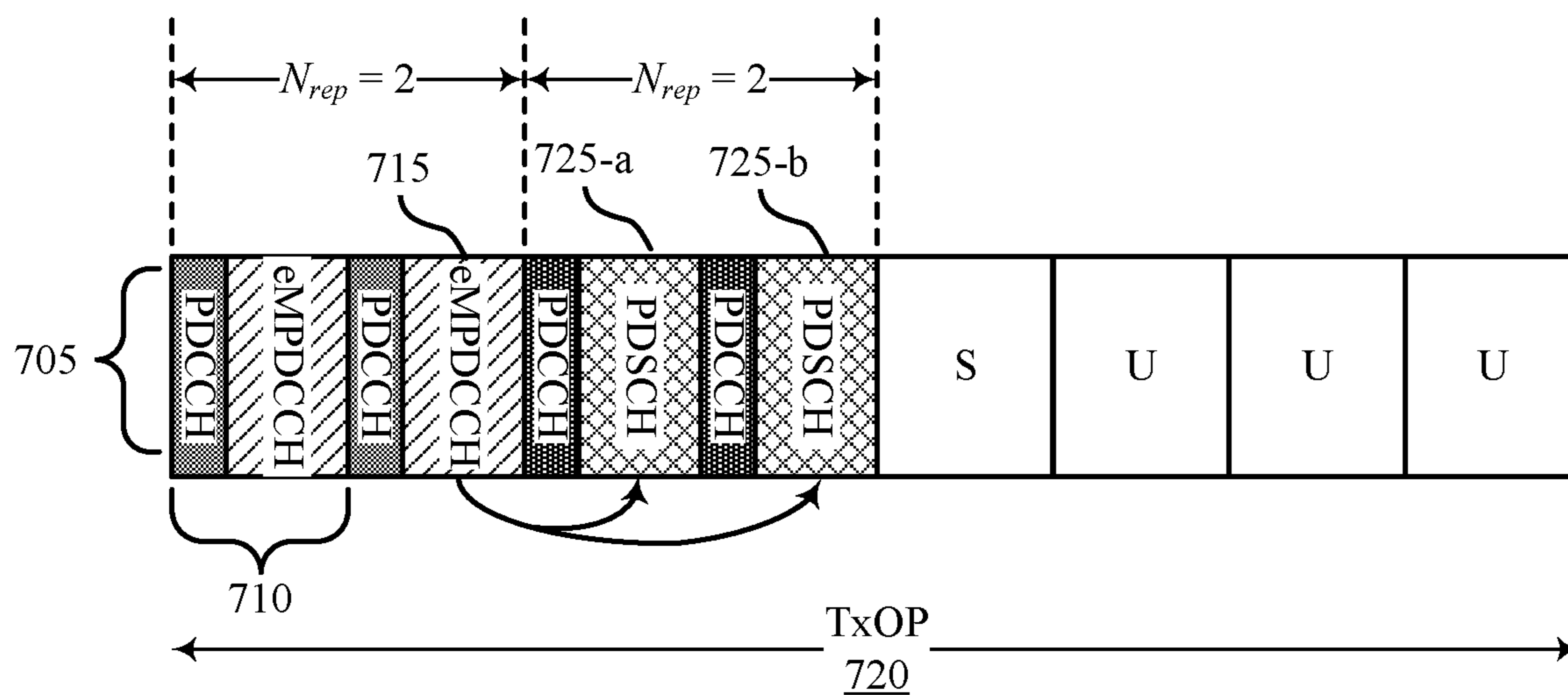


FIG. 7

700

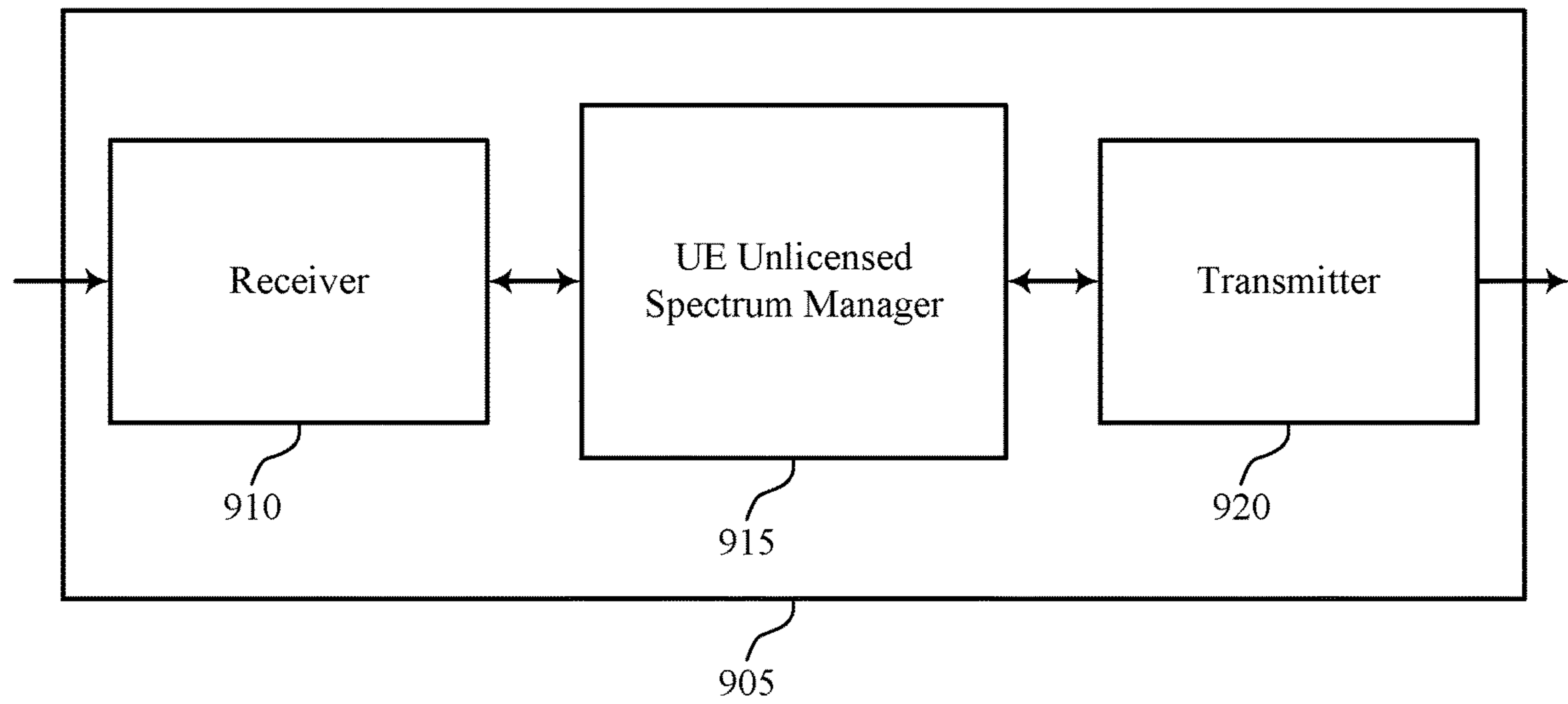


FIG. 9

900

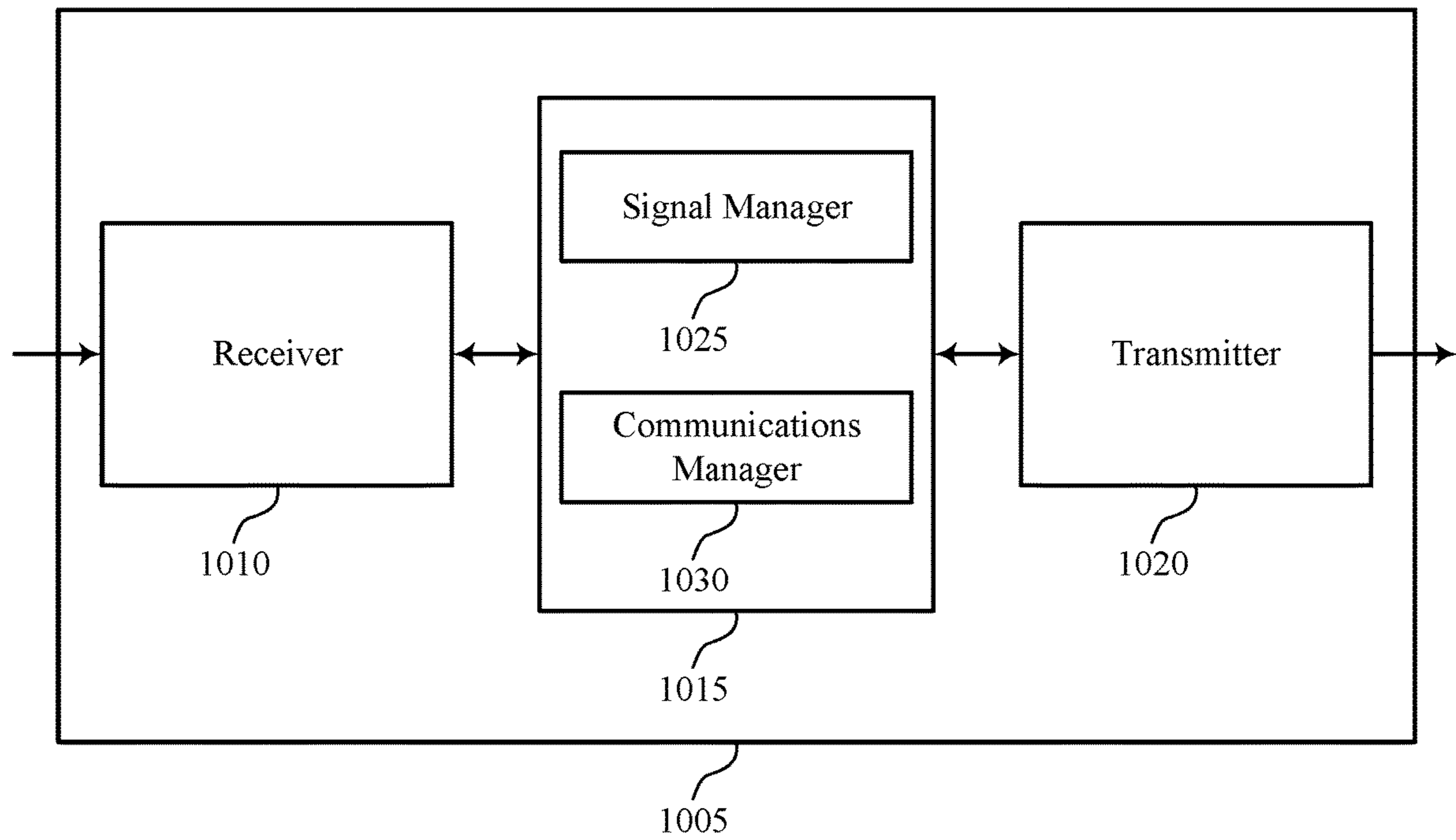


FIG. 10

1000

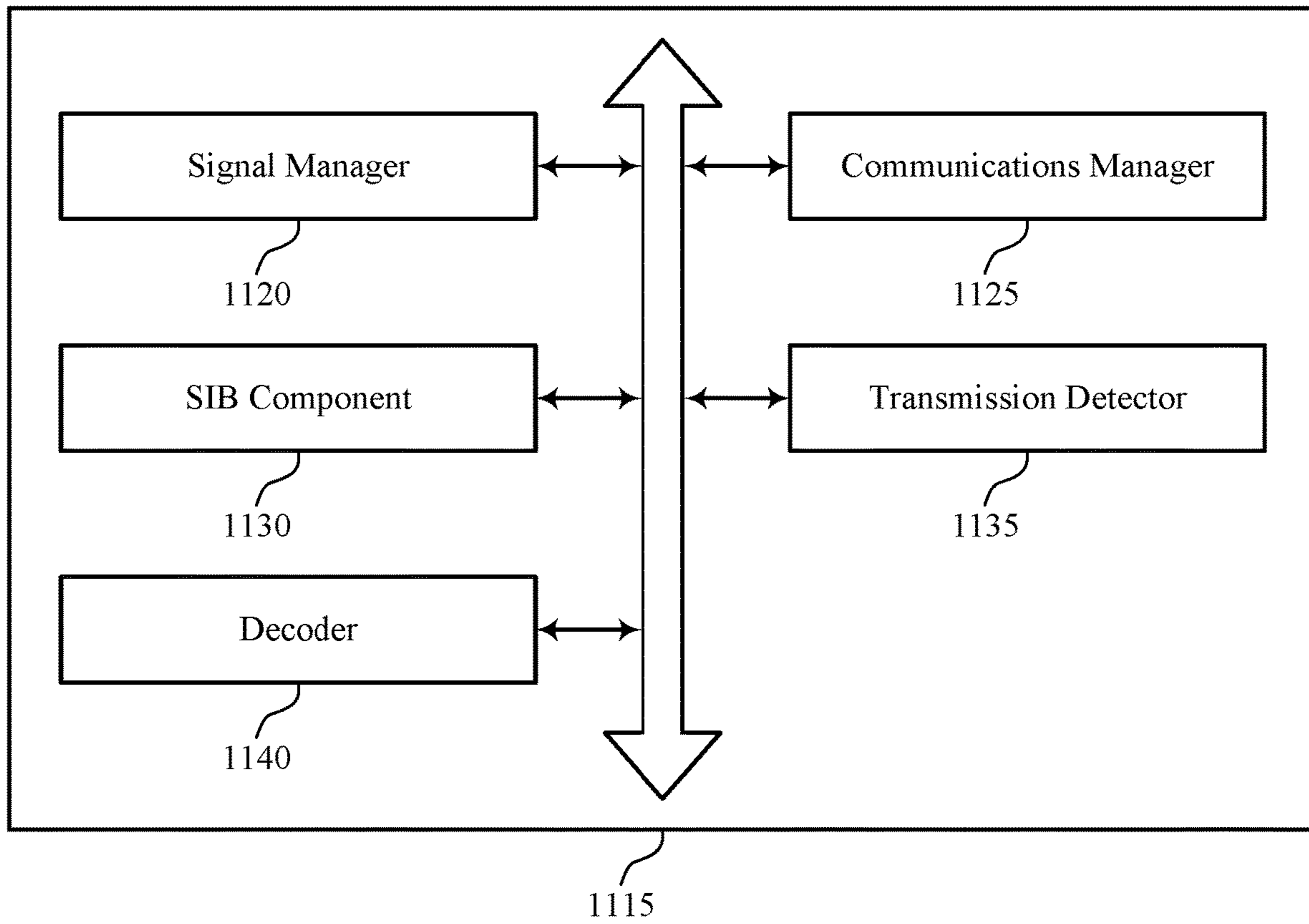


FIG. 11

1100

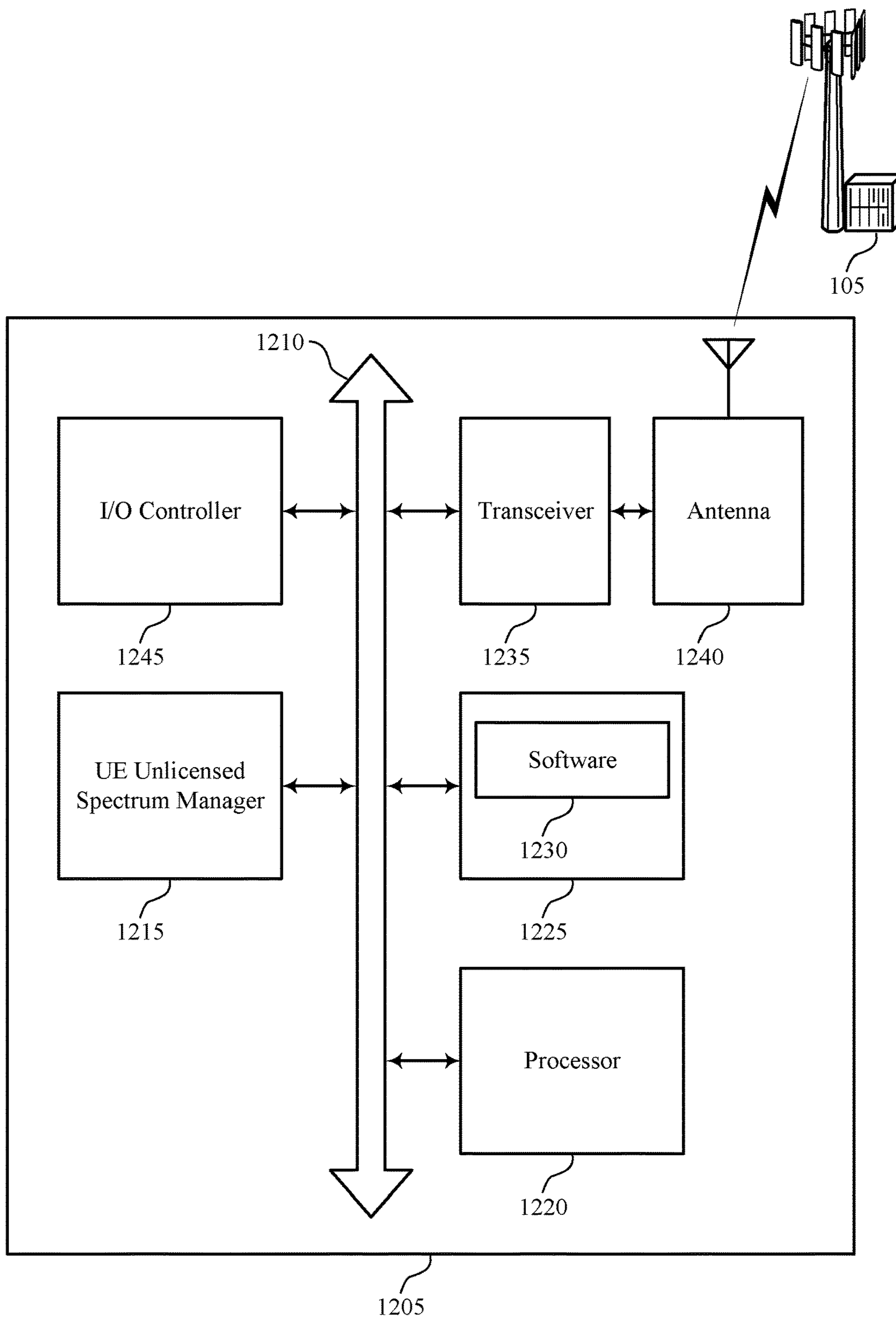


FIG. 12

1200

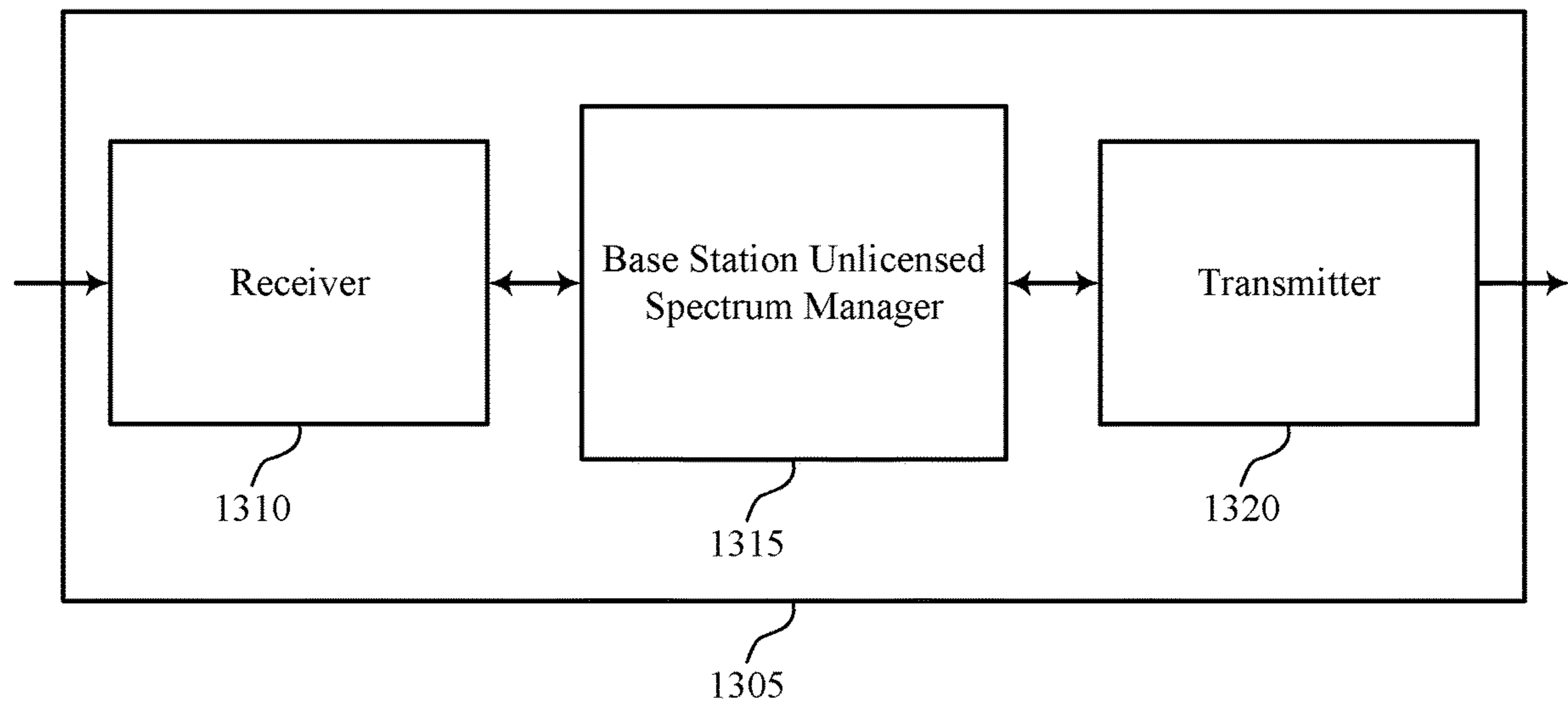


FIG. 13

1300

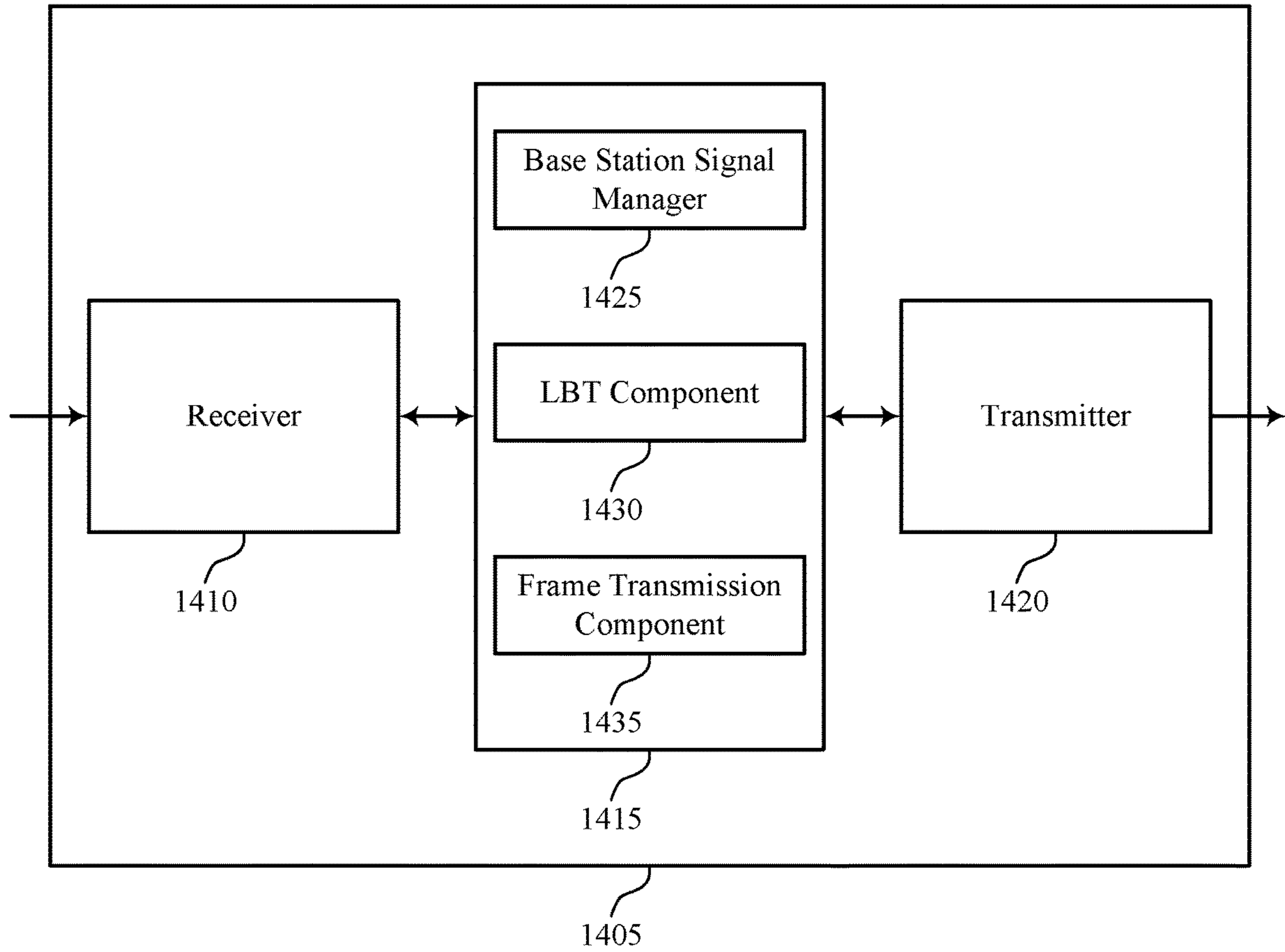


FIG. 14

1400

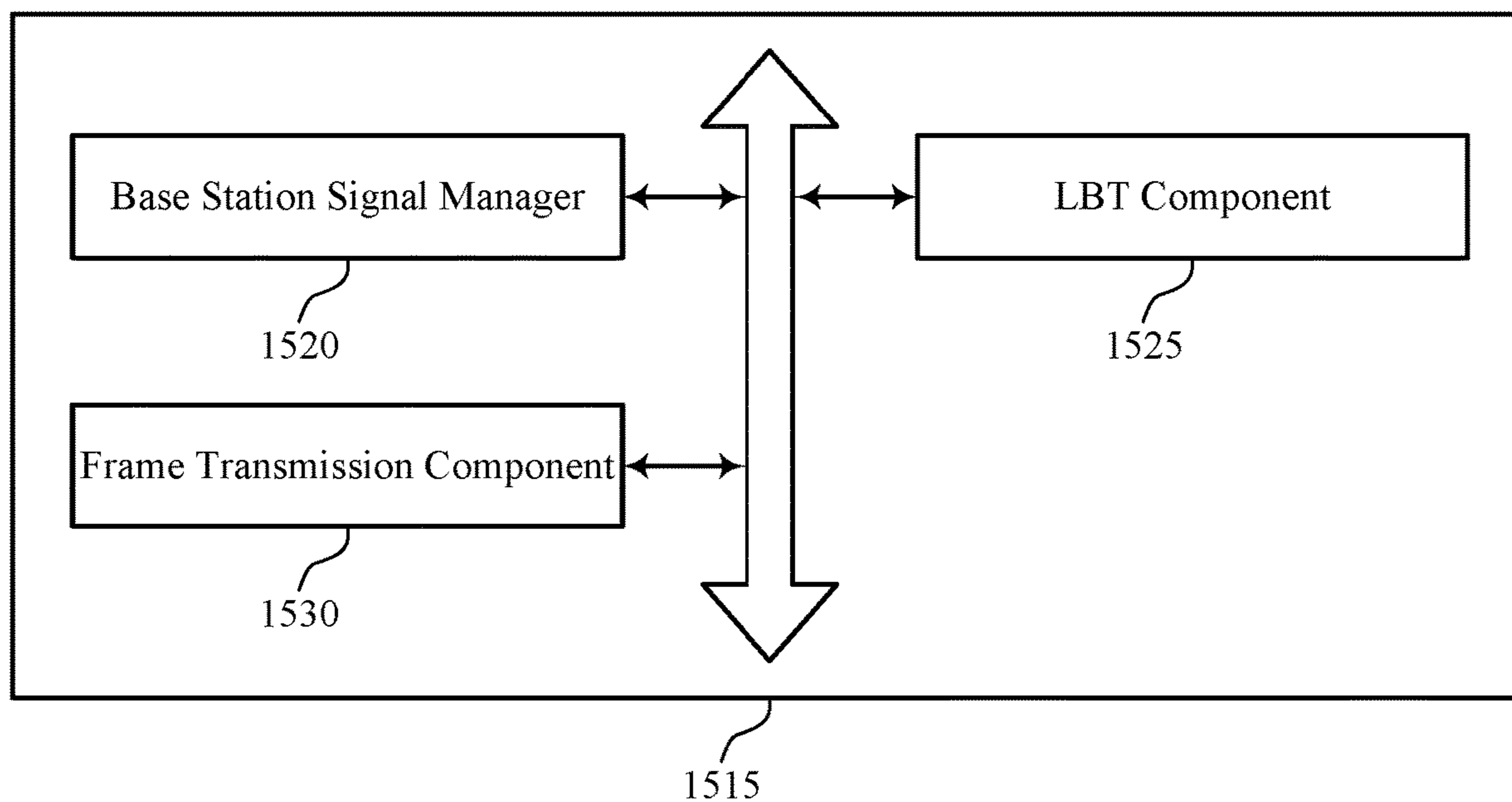


FIG. 15

1500

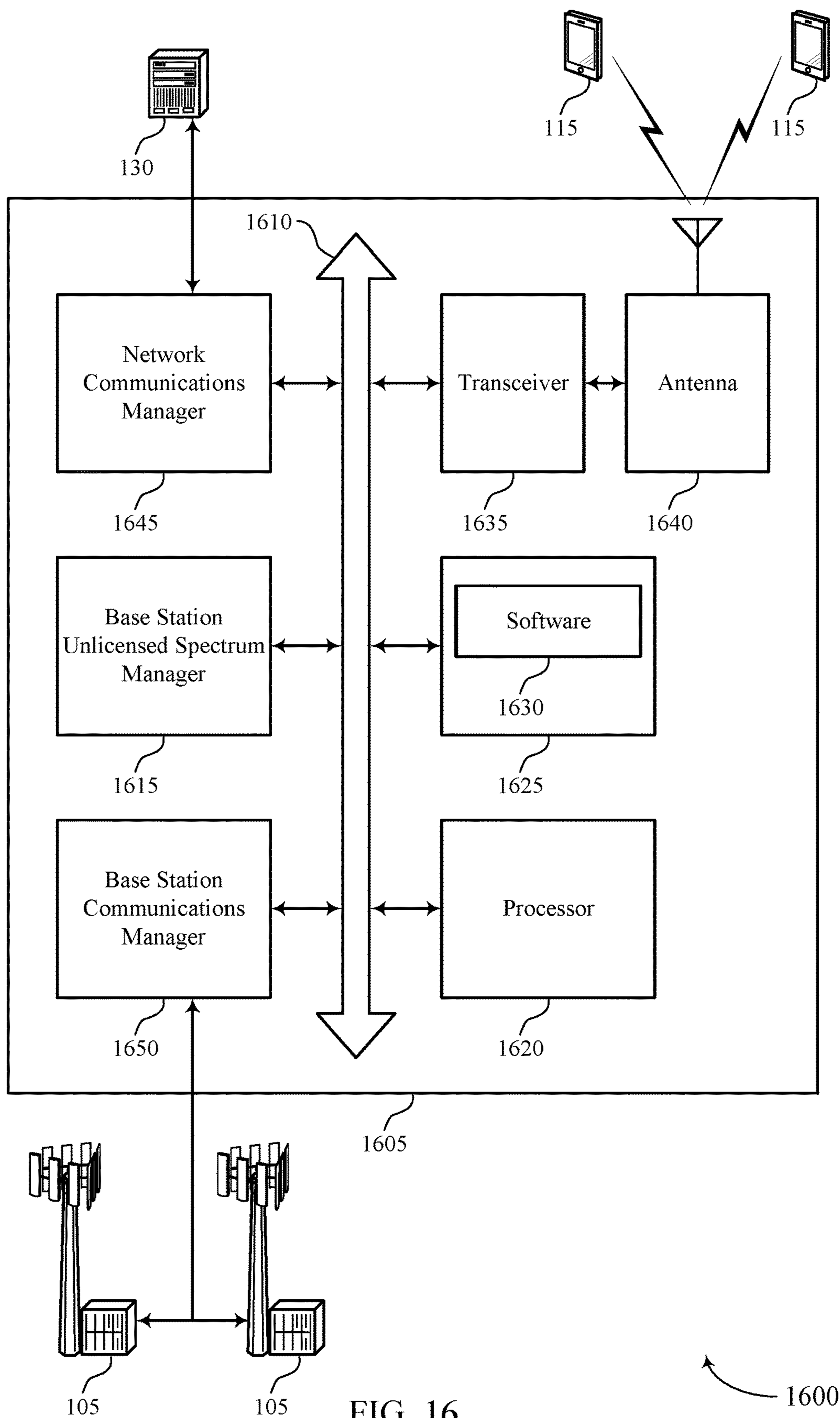


FIG. 16

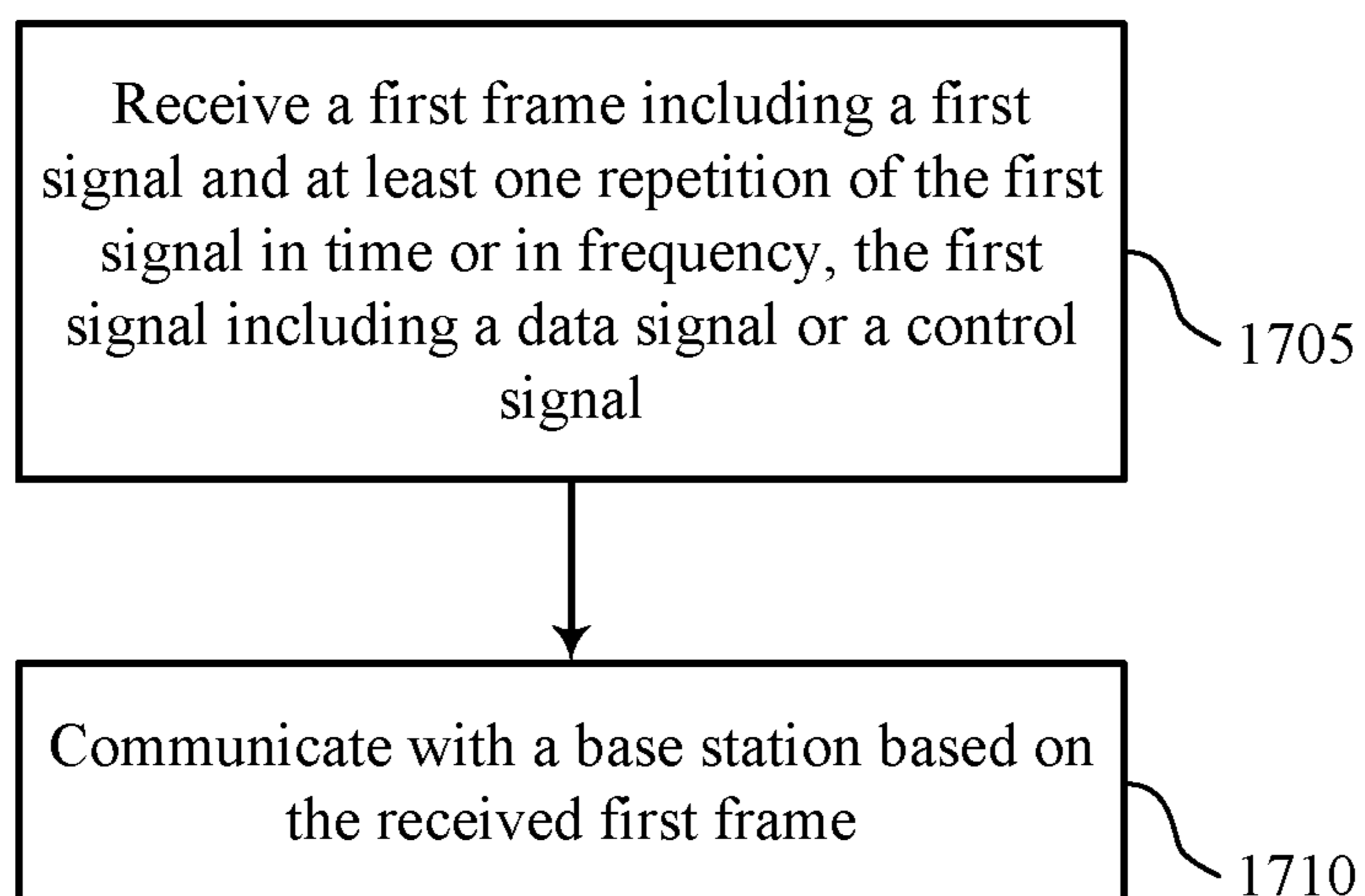


FIG. 17

1700

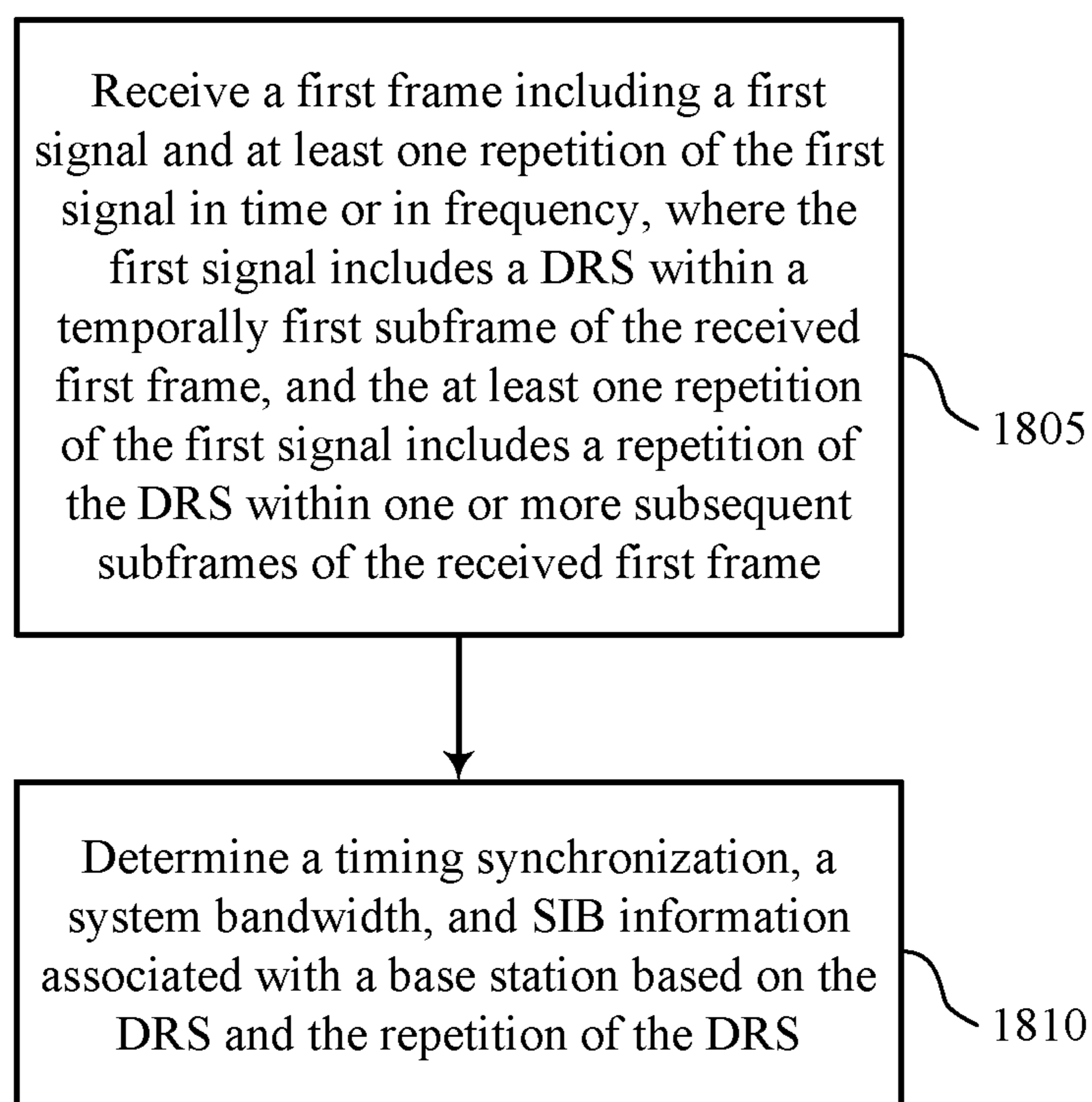


FIG. 18

1800

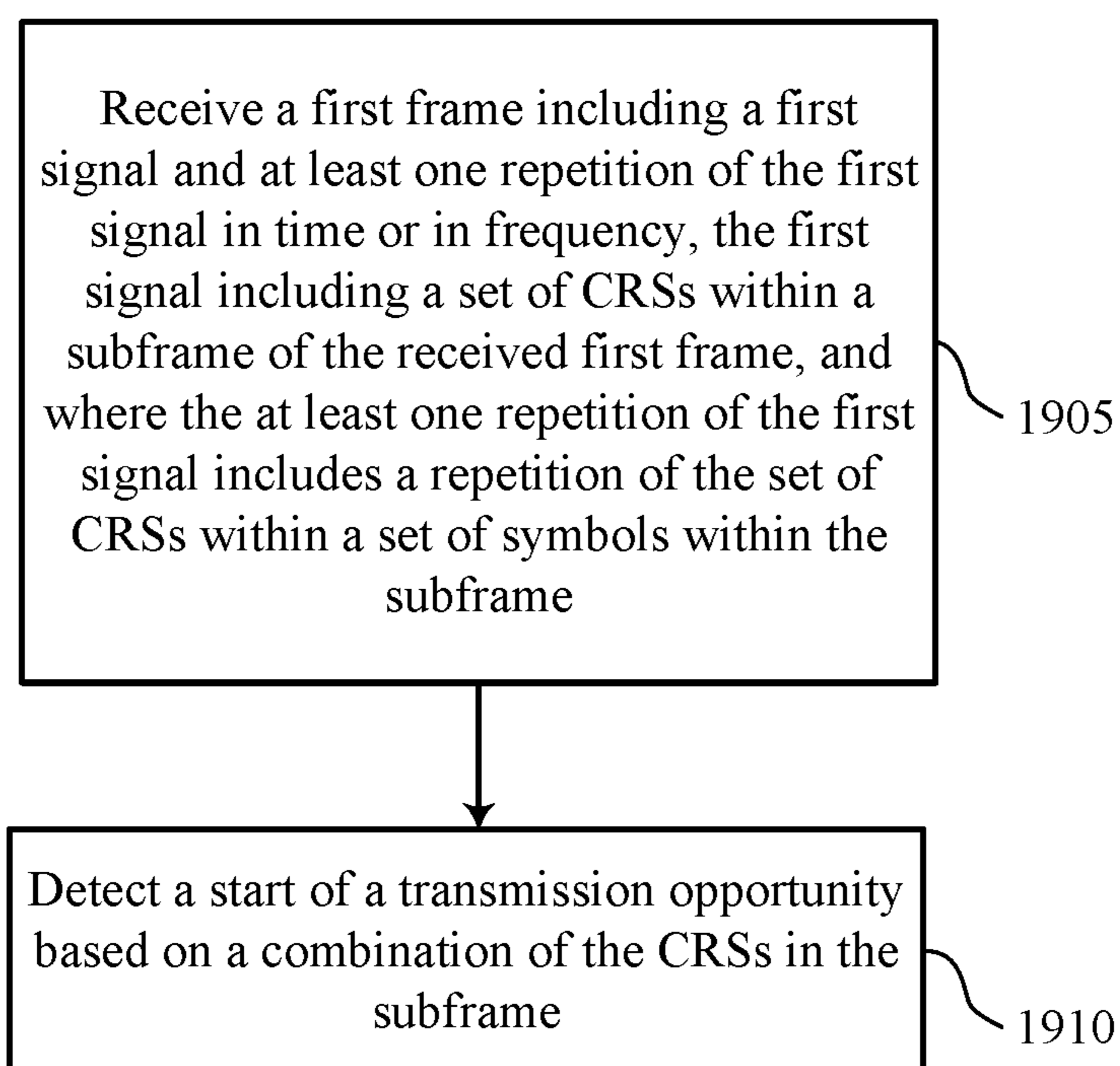


FIG. 19

1900

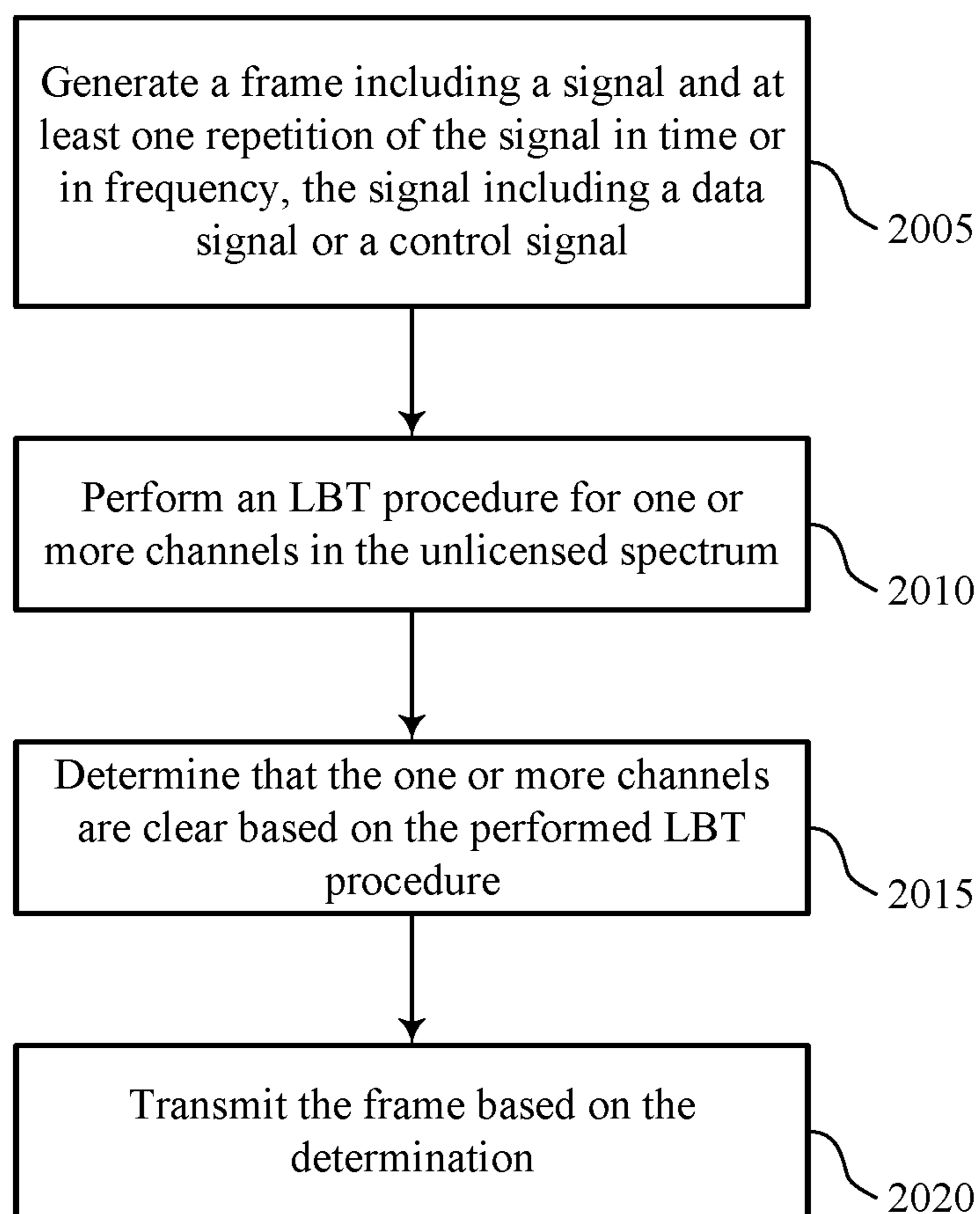


FIG. 20

2000

**UNLICENSED SPECTRUM COVERAGE
ENHANCEMENT FOR INDUSTRIAL
INTERNET OF THINGS**

CROSS REFERENCES

The present application for patent claims priority to U.S. Provisional Patent Application No. 62/415,316 by Liu, et al., entitled "Unlicensed Spectrum Coverage Enhancement for Industrial Internet of Things," filed Oct. 31, 2016, assigned to the assignee hereof, and is hereby expressly incorporated by reference herein in its entirety.

TECHNICAL FIELD

This disclosure relates to wireless communication systems, and more specifically to unlicensed spectrum coverage enhancement for industrial internet of things (IoT).

DESCRIPTION OF THE RELATED
TECHNOLOGY

Wireless communications systems are widely deployed to provide various types of communication content such as voice, video, packet data, messaging, broadcast, and so on. These systems may be capable of supporting communication with multiple users by sharing the available system resources (such as time, frequency, and power). Examples of such multiple-access systems include code division multiple access (CDMA) systems, time division multiple access (TDMA) systems, frequency division multiple access (FDMA) systems, and orthogonal frequency division multiple access (OFDMA) systems, (such as a Long Term Evolution (LTE) system, or a New Radio (NR) system). A wireless multiple-access communications system may include a number of base stations or access network nodes, each simultaneously supporting communication for multiple communication devices, which may be otherwise known as user equipment (UE).

Some wireless communications systems may be used to support techniques that provide various devices and common objects with connectivity for communicating data, often referred to as the IoT. In some examples, these wireless communications systems may operate using a first radio access technology (RAT), such as LTE or LTE-Advanced (LTE-A), and may include a number of base stations, each simultaneously supporting communications with multiple devices, such as IoT devices or UEs. These base stations and UEs operating in accordance with the first RAT also may communicate in a shared or unlicensed radio frequency (RF) spectrum.

The application of the IoT in an industrial setting, such as manufacturing plants, may increase operational efficiency and introduce more flexible production techniques. However, benefits gained from industrial IoT schemes also may be reliant on the use of unlicensed RF spectrum due to costs associated with licensed RF spectrum use. As a result, it may be beneficial to implement coverage and link budget enhancement schemes for wireless communications systems using unlicensed spectrum to ensure connectivity for devices in industrial IoT settings.

SUMMARY

The systems, methods and devices of this disclosure each have several innovative aspects, no single one of which is solely responsible for the desirable attributes disclosed herein.

A method of wireless communication at a device using unlicensed spectrum is described. The method may include receiving a first frame including a first signal and at least one repetition of the first signal in time or in frequency, the first signal including a data signal or a control signal, and communicating with a base station based at least in part on the received first frame.

An apparatus for wireless communication at a device using unlicensed spectrum is described. The apparatus may include a processor, memory in electronic communication with the processor, and instructions stored in the memory. The instructions may be operable to cause the processor to receive a first frame including a first signal and at least one repetition of the first signal in time or in frequency, the first signal including a data signal or a control signal, and communicate with a base station based at least in part on the received first frame.

Another apparatus for wireless communication at a device using unlicensed spectrum is described. The apparatus may include means for receiving a first frame including a first signal and at least one repetition of the first signal in time or in frequency, the first signal including a data signal or a control signal, and means for communicating with a base station based at least in part on the received first frame.

A non-transitory computer readable medium for wireless communication at a device using unlicensed spectrum is described. The non-transitory computer-readable medium may include instructions operable to cause a processor to receive a first frame including a first signal and at least one repetition of the first signal in time or in frequency, the first signal including a data signal or a control signal, and communicate with a base station based at least in part on the received first frame.

In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the first signal includes a discovery reference signal (DRS) within a temporally first subframe of the received first frame, the at least one repetition of the first signal including a repetition of the DRS within one or more subsequent subframes of the received first frame. Some examples of the method, apparatus, and non-transitory computer-readable medium described above may further include processes, features, means, or instructions for determining a timing synchronization, a system bandwidth, and system information block (SIB) information associated with the base station based at least in part on the DRS and the repetition of the DRS. In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the first signal includes a synchronization signal within a DRS subframe of the received first frame, and the at least one repetition of the first signal includes a repetition of the synchronization signal within the DRS subframe.

In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the first signal includes an enhanced machine type communication (MTC) physical downlink control channel (eMPDCCH) within a temporally second subframe of the received first frame. Some examples of the method, apparatus, and non-transitory computer-readable medium described above may further include processes, features, means, or instructions for identifying a set of system information blocks (SIBs) within a subsequent subframe of the received first frame based at least in part on the eMPDCCH.

In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the first signal includes a set of cell-specific reference signals (CRSs) within a temporally first subframe of the received

first frame, where the at least one repetition of the first signal includes a repetition of the CRSs over a set of subsequent subframes. Some examples of the method, apparatus, and non-transitory computer-readable medium described above may further include processes, features, means, or instructions for detecting a start of a transmission opportunity based at least on a combination of the set of CRSs in the temporally first subframe.

In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the first signal includes a set of CRSs within a subframe of the received first frame, where the at least one repetition of the first signal includes a repetition of the set of CRSs within a set of symbols within the subframe. Some examples of the method, apparatus, and non-transitory computer-readable medium described above may further include processes, features, means, or instructions for detecting a start of a transmission opportunity based at least in part on a combination of the CRSs in the subframe.

In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the first signal includes a physical downlink control channel (PDCCH) within a subframe of the received first frame, where the at least one repetition of the first signal includes a repetition of the PDCCH within a same transmission opportunity as the subframe. Some examples of the method, apparatus, and non-transitory computer-readable medium described above may further include processes, features, means, or instructions for identifying a starting point of the PDCCH based at least in part on the subframe. Some examples of the method, apparatus, and non-transitory computer-readable medium described above may further include processes, features, means, or instructions for decoding the first frame based at least in part on the identified starting point of the PDCCH and an accumulation of the PDCCH within the same transmission opportunity of the subframe.

In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the first signal includes a physical downlink control channel (PDCCH) within a temporally first subframe of the received first frame, where the temporally first subframe may be within a first transmission opportunity, and the at least one repetition of the first signal includes a repetition of the PDCCH within a subsequent transmission opportunity. Some examples of the method, apparatus, and non-transitory computer-readable medium described above may further include processes, features, means, or instructions for identifying a starting point of the PDCCH based at least in part on the temporally first subframe. Some examples of the method, apparatus, and non-transitory computer-readable medium described above may further include processes, features, means, or instructions for decoding the first frame based at least in part on the starting point of the PDCCH and an accumulation of the PDCCH within the first transmission opportunity and the subsequent transmission opportunity.

In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the first signal includes an enhanced machine type communication (MTC) physical downlink control channel (eMPDCCH) within a subframe of the received first frame, where the at least one repetition of the first signal includes a frequency domain repetition of the eMPDCCH within a transmission opportunity as the subframe. Some examples of the method, apparatus, and non-transitory computer-readable medium described above may further include processes, features, means, or instructions for identifying a starting point of the eMPDCCH based at least in part on the subframe. Some

examples of the method, apparatus, and non-transitory computer-readable medium described above may further include processes, features, means, or instructions for decoding the first frame based at least in part on the starting point of the eMPDCCH and an accumulation of the eMPDCCH within the transmission opportunity of the subframe.

In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the first signal includes a physical downlink shared channel (PDSCH) within a first subframe of the received first frame, where the at least one repetition of the first signal includes a repetition of the PDSCH within additional subframes of a transmission opportunity including the first subframe. Some examples of the method, apparatus, and non-transitory computer-readable medium described above may further include processes, features, means, or instructions for decoding the PDSCH based at least in part on the PDSCH within the first subframe and the repetition of the PDSCH within the additional subframes.

In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the first signal includes a physical downlink shared channel (PDSCH) within a subframe of the received first frame, where the at least one repetition of the first signal includes a time-domain repetition of the PDSCH within a transmission opportunity including the subframe and a subsequent transmission opportunity. In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the communicating includes: transmitting a second frame including a second signal and at least one repetition of the second signal in time, the second signal including a physical uplink shared channel (PUSCH), where the at least one repetition of the second signal may be based at least in part on the received first signal.

In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the communicating includes: transmitting a second frame including a second signal and at least one repetition of the second signal, the second signal including a physical uplink control channel (PUCCH), where the at least one repetition of the second signal may be located within an uplink subframe following a special subframe. Some examples of the method, apparatus, and non-transitory computer-readable medium described above may further include processes, features, means, or instructions for transmitting a second frame including a second signal and at least one repetition of the second signal, the second signal including a physical random access channel (PRACH), where the second signal and the at least one repetition of the second signal may be located within contiguous subframes. In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the first frame includes a semi-statically configured uplink-to-downlink ratio.

A method of wireless communication at a device using unlicensed spectrum is described. The method may include generating a frame including a signal and at least one repetition of the signal in time or in frequency, the signal including a data signal or a control signal, performing a listen before talk (LBT) procedure for one or more channels in the unlicensed spectrum, determining that the one or more channels are clear based at least in part on the performed LBT procedure, and transmitting the frame based at least in part on the determination.

An apparatus for wireless communication at a device using unlicensed spectrum is described. The apparatus may include a processor, memory in electronic communication

with the processor, and instructions stored in the memory. The instructions may be operable to cause the processor to generate a frame including a signal and at least one repetition of the signal in time or in frequency, the signal including a data signal or a control signal, perform an LBT procedure for one or more channels in the unlicensed spectrum, determine that the one or more channels are clear based at least in part on the performed LBT procedure, and transmit the frame based at least in part on the determination.

Another apparatus for wireless communication at a device using unlicensed spectrum is described. The apparatus may include means for generating a frame including a signal and at least one repetition of the signal in time or in frequency, the signal including a data signal or a control signal, means for performing an LBT procedure for one or more channels in the unlicensed spectrum, means for determining that the one or more channels are clear based at least in part on the performed LBT procedure, and means for transmitting the frame based at least in part on the determination.

A non-transitory computer readable medium for wireless communication at a device using unlicensed spectrum is described. The non-transitory computer-readable medium may include instructions operable to cause a processor to generate a frame including a signal and at least one repetition of the signal in time or in frequency, the signal including a data signal or a control signal, perform an LBT procedure for one or more channels in the unlicensed spectrum, determine that the one or more channels are clear based at least in part on the performed LBT procedure, and transmit the frame based at least in part on the determination.

In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the signal includes a DRS within a temporally first subframe of the frame, where the at least one repetition of the signal includes a repetition of the DRS within one or more subsequent subframes of the frame. In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the signal includes a synchronization signal within a DRS subframe of the frame, where the at least one repetition of the signal includes a repetition of the synchronization signal within the DRS subframe.

In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the signal includes an eMPDCCH within a temporally second subframe of the frame. In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the signal includes a set of CRSs within a temporally first subframe of the frame, where the at least one repetition of the signal includes a repetition of the CRSs over a set of subsequent subframes.

In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the signal includes an eMPDCCH within a subframe of the frame, where the at least one repetition of the signal includes a frequency domain repetition of the eMPDCCH within a transmission opportunity as the subframe. In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the signal includes a PDSCH within a first subframe of the frame, where the at least one repetition of the signal includes a repetition of the PDSCH within additional subframes of a transmission opportunity including the first subframe. In some examples of the method, apparatus, and non-transitory computer-readable medium described above, the signal includes a PDSCH within a subframe of the frame, where the at least one repetition of the signal includes a time-domain repeti-

tion of the PDSCH within a transmission opportunity including the subframe and a subsequent transmission opportunity.

Details of one or more implementations of the subject matter described in this disclosure are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings and the claims. Note that the relative dimensions of the following figures may not be drawn to scale.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an example of a wireless communications system that supports unlicensed spectrum coverage enhancement for industrial Internet of Things (IoT).

FIG. 2 illustrates an example of a wireless communications system that supports unlicensed spectrum coverage enhancement for industrial IoT.

FIG. 3 illustrates an example of discovery reference signal (DRS) subframes that support unlicensed spectrum coverage enhancement for industrial IoT.

FIG. 4 illustrates an example of a subframe including repetitions of a cell-specific reference signal (CRS) that supports unlicensed spectrum coverage enhancement for industrial IoT.

FIGS. 5 through 8 illustrate examples of frame configurations that support unlicensed spectrum coverage enhancement for industrial IoT.

FIGS. 9 through 11 show block diagrams of devices that support unlicensed spectrum coverage enhancement for industrial IoT.

FIG. 12 illustrates a block diagram of a system including a user equipment (UE) that supports unlicensed spectrum coverage enhancement for industrial IoT.

FIGS. 13 through 15 show block diagrams of devices that support unlicensed spectrum coverage enhancement for industrial IoT.

FIG. 16 illustrates a block diagram of a system including a base station that supports unlicensed spectrum coverage enhancement for industrial IoT.

FIGS. 17 through 20 illustrate methods for unlicensed spectrum coverage enhancement for industrial IoT.

Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

The following description is directed to certain implementations for the purposes of describing the innovative aspects of this disclosure. However, a person having ordinary skill in the art will readily recognize that the teachings herein can be applied in a multitude of different ways. The described implementations may be implemented in any device, system or network that is capable of transmitting and receiving radio frequency (RF) signals according to any of the Institute of Electrical and Electronics Engineers (IEEE) 16.11 standards, or any of the IEEE 802.11 standards, the Bluetooth® standard, code division multiple access (CDMA), frequency division multiple access (FDMA), time division multiple access (TDMA), Global System for Mobile communications (GSM), GSM/General Packet Radio Service (GPRS), Enhanced Data GSM Environment (EDGE), Terrestrial Trunked Radio (TETRA), Wideband-CDMA (W-CDMA), Evolution Data Optimized (EV-DO), 1×EV-DO, EV-DO Rev A, EV-DO Rev B, High Speed Packet Access (HSPA), High Speed Downlink Packet Access (HSDPA), High Speed Uplink Packet Access

(HSUPA), Evolved High Speed Packet Access (HSPA+), Long Term Evolution (LTE), LTE-Advanced (LTE-A), Advanced Mobile Phone Service (AMPS) or other known signals that are used to communicate within a wireless, cellular or Internet of Things (IoT) network, such as a system utilizing 3G, 4G or 5G, or further implementations thereof, technology.

Generally, the described techniques provide for the repetition of multiple symbols to increase a device's ability to synchronize and communicate using unlicensed spectrum. For example, a base station may schedule a frame that includes multiple repetitions, in time or frequency, of a control or data signal. After determining that a channel within unlicensed spectrum is clear using a listen before talk (LBT) procedure, the base station may broadcast or transmit the frame to one or more devices, such as a user equipment (UE) or machine type communication (MTC) device. In some cases, the frame may include multiple repetitions of a discovery reference signal (DRS), and may be broadcast by the base station to enable synchronization with the base station by a UE. In other examples, the signal may include repetitions of a cell-specific reference signal (CRS), and upon receipt of the CRSs, a UE may identify a start of a transmission opportunity (TxOP) in unlicensed spectrum. Other signals, such as downlink control and shared channels, may be repeated within a frame transmission in a similar manner to ensure receipt by the UE. Additionally, the UE may transmit a frame that includes repetitions of a control or data signal when communicating with the base station.

In some cases, reliance on unlicensed radio frequency spectrum for wireless communications is associated with particular deployments and market needs. For example, licensed spectrum may be too costly to use for an IoT network operated by a particular industry, manufacturer, and the like. Such industrial applications of IoT may accordingly focus on communications schemes that use wideband or in-band operation in an unlicensed or contention-based spectrum.

Wireless communications systems for industrial IoT may be associated with a number of coverage requirements to ensure efficient operation. As an example, industry applications including automated guided vehicles (AGVs) (such as AGVs used for cargo handling or robotic vehicles in a factory) may have a minimum operational bandwidth requirement (such as 150 kbps). There also may be requirements for minimum coverage provided by wireless communications systems using unlicensed spectrum, such as three times the coverage provided by Wi-Fi, for example, with corresponding signal gains (such as at least a 16 dB gain over Wi-Fi). As a result, techniques to achieve coverage enhancement, particularly for downlink signaling, in unlicensed spectrum may be desirable to ensure operation within environments or deployments associated with operational requirements.

Operational requirements in an industrial IoT environment may be met through a repetition of a number of data and control signals within uplink and downlink transmissions. That is, through the repetition of various signals (such as DRSs, CRSs, physical uplink and downlink control channels, physical uplink and downlink shared channels, and other data or control signals), a signal-to-noise ratio (SNR) may be increased to allow for greater coverage and operability for wireless devices using unlicensed spectrum.

For example, repetitions of a DRS may enable a device, such as a UE or MTC device, to identify synchronization timing or a system bandwidth associated with a base station. In such cases, a base station may first complete a clear

channel assessment (CCA) (such as an LBT procedure) to ensure a channel is not occupied with wireless traffic, and then broadcast multiple subframes, where each subframe is used for repetitions of DRS. These subframes may include 14 orthogonal frequency division multiplexing (OFDM) symbols that are used to transmit DRS. In some other examples, such as after synchronization, repetitions of CRS may be used by a UE to detect a start of a TxOP. Repetition of control and data signals may be transmitted by both base stations and UEs.

Particular implementations of the subject matter described in this disclosure can be implemented to realize one or more of the following potential advantages. A repetition of a data or control signal provides for an increased SNR associated with those signals. As a result, the increased SNR may improve overall connectivity for wireless devices. The increased SNR may be further applied to situations where a particular link budget may be used. The repetition of DRS, control, and data channels may further ensure a backward compatibility with legacy devices. That is, legacy devices (or devices that may not be configured to operate in a coverage enhancement mode) may operate without changes to the legacy devices, as they may continue to utilize signals that are present without the repetition of the various signals described herein. Additionally, devices that are capable of using the repetitions of the signals (such as IoT devices), may use these repetitions of DRS, or data and control channels for increased coverage operations, thereby enabling coexistence of different types of devices having various capabilities or configurations within the same system. Repetitions of a primary synchronization signal (PSS) and CRS enables transmission detection in unlicensed spectrum for increased coverage, enabling a UE to determine a starting point for a TxOP within a system.

Aspects of the disclosure are initially described in the context of a wireless communications system. Further examples are then provided of frames and subframes that include multiple transmissions of various control and data signals. Aspects of the disclosure are further illustrated by and described with reference to apparatus diagrams, system diagrams, and flowcharts that relate to unlicensed spectrum coverage enhancement for industrial IoT.

FIG. 1 illustrates an example of a wireless communications system **100** that supports unlicensed spectrum coverage enhancement for industrial IoT. The wireless communications system **100** includes base stations **105**, UEs **115**, and a core network **130**. In some examples, the wireless communications system **100** may be an LTE (or LTE-A) network, or a New Radio (NR) network. In some cases, the wireless communications system **100** may support enhanced broadband communications, ultra-reliable (i.e., mission critical) communications, low latency communications, and communications with low-cost and low-complexity devices. The wireless communications system **100** may further enable synchronization and connectivity of devices operating in unlicensed spectrum through the repetition of data and control signals.

The base stations **105** may wirelessly communicate with the UEs **115** via one or more base station antennas. Each base station **105** may provide communication coverage for a respective geographic coverage area **110**. Wireless communication links **125** shown in the wireless communications system **100** may include uplink transmissions from a UE **115** to a base station **105**, or downlink transmissions, from a base station **105** to a UE **115**. Control information and data may be multiplexed on an uplink channel or downlink according to various techniques. Control information and data may be

multiplexed on a downlink channel, for example, using time division multiplexing (TDM) techniques, frequency division multiplexing (FDM) techniques, or hybrid TDM-FDM techniques. In some examples, the control information transmitted during a transmission time interval (TTI) of a downlink channel may be distributed between different control regions in a cascaded manner (such as between a common control region and one or more UE-specific control regions).

The UEs **115** may be dispersed throughout the wireless communications system **100**, and each UE **115** may be stationary or mobile. A UE **115** also may be referred to as a mobile station, a subscriber station, a mobile unit, a subscriber unit, a wireless unit, a remote unit, a mobile device, a wireless device, a wireless communications device, a remote device, a mobile subscriber station, an access terminal, a mobile terminal, a wireless terminal, a remote terminal, a handset, a user agent, a mobile client, a client, or some other suitable terminology. A UE **115** also may be a cellular phone, a personal digital assistant (PDA), a wireless modem, a wireless communication device, a handheld device, a tablet computer, a laptop computer, a cordless phone, a personal electronic device, a handheld device, a personal computer, a wireless local loop (WLL) station, an IoT device, an Internet of Everything (IoE) device, a machine type communication (MTC) device, an appliance, an automobile, or the like.

In some cases, a UE **115** also may be able to communicate directly with other UEs (such as using a peer-to-peer (P2P) or device-to-device (D2D) protocol). One or more of a group of the UEs **115** utilizing D2D communications may be within the geographic coverage area **110** of a cell. Other UEs **115** in such a group may be outside the geographic coverage area **110** of a cell, or otherwise unable to receive transmissions from a base station **105**. In some cases, groups of UEs **115** communicating via D2D communications may utilize a one-to-many (1:M) system in which each UE **115** transmits to every other UE **115** in the group. In some cases, a base station **105** facilitates the scheduling of resources for D2D communications. In some other cases, D2D communications are carried out independent of a base station **105**.

Some UEs **115**, such as MTC or IoT devices, may be low cost or low complexity devices, and may provide for automated communication between machines, i.e., Machine-to-Machine (M2M) communication. M2M or MTC may refer to data communication technologies that allow devices to communicate with one another or a base station without human intervention. For example, M2M or MTC may refer to communications from devices that integrate sensors or meters to measure or capture information and relay that information to a central server or application program that can make use of the information or present the information to humans interacting with the program or application. Some UEs **115** may be designed to collect information or enable automated behavior of machines. Examples of applications for MTC devices include smart metering, inventory monitoring, water level monitoring, equipment monitoring, healthcare monitoring, wildlife monitoring, weather and geological event monitoring, fleet management and tracking, remote security sensing, physical access control, and transaction-based business charging.

The base stations **105** may communicate with the core network **130** and with one another. For example, base stations **105** may interface with the core network **130** through backhaul links **132** (such as S1, etc.). The base stations **105** may communicate with one another over backhaul links **134** (such as X2, etc.) either directly or indirectly (such as through core network **130**). The base stations **105**

may perform radio configuration and scheduling for communication with UEs **115**, or may operate under the control of a base station controller (not shown). In some examples, base stations **105** may be macro cells, small cells, hot spots, or the like. The base stations **105** also may be referred to as eNodeBs (eNBs) **105**.

In some cases, the wireless communications system **100** may utilize both licensed and unlicensed radio frequency spectrum bands. For example, the wireless communications system **100** may employ access technology in an unlicensed band such as the 5 Ghz Industrial, Scientific, and Medical (ISM) band. When operating in unlicensed radio frequency spectrum bands, wireless devices such as base stations **105** and UEs **115** may employ LBT procedures to ensure the channel is clear before transmitting data. In some cases, operations in unlicensed bands may be based on a carrier aggregation (CA) configuration in conjunction with component carriers (CCs) operating in a licensed band. Operations in unlicensed spectrum may include downlink transmissions, uplink transmissions, or both. Duplexing in unlicensed spectrum may be based on frequency division duplexing (FDD), time division duplexing (TDD) or a combination of both.

A UE **115** attempting to access a wireless network may perform an initial cell search by detecting a PSS from a base station **105**. The PSS may enable synchronization of slot timing and may indicate a physical layer identity value. The UE **115** may then receive a secondary synchronization signal (SSS). The SSS may enable radio frame synchronization, and may provide a cell identity value, which may be combined with the physical layer identity value to identify the cell. The SSS also may enable detection of a duplexing mode and a cyclic prefix length. Some systems, such as TDD systems, may transmit an SSS but not a PSS. Both the PSS and the SSS may be located in the central **62** and **72** subcarriers of a carrier, respectively. After receiving the PSS and SSS, the UE **115** may receive a master information block (MIB), which may be transmitted in the physical broadcast channel (PBCH). The MIB may contain system bandwidth information, a system frame number (SFN), and a physical hybrid automatic repeat request (HARD) indicator channel (PHICH) configuration. After decoding the MIB, the UE **115** may receive one or more system information blocks (SIBs). For example, SIB1 may contain cell access parameters and scheduling information for other SIBs. Decoding SIB1 may enable the UE **115** to receive SIB2. SIB2 may contain radio resource control (RRC) configuration information related to random access channel (RACH) procedures, paging, physical uplink control channel (PUCCH), physical uplink shared channel (PUSCH), power control, sounding reference signals (SRSs), and cell barring.

Wireless communications systems may use a number of different frame configurations for uplink and downlink communications, and the pattern of subdivisions of radio frames in the time domain may be referred to as a frame structure. For example, the frame structure can be type 1 or type 2, where type 1 may be applicable to both full duplex and half duplex FDD, while type 2 may be applicable to TDD. Frame structure type 3 may include a burst of downlink subframes, followed by a special subframe (such as a subframe between downlink and uplink subframes that includes a downlink pilot time slot (DwPTS) region, a guard period, and an uplink pilot time slot (UpPTS) region). The special subframe may followed by a burst of uplink subframes. In some cases, the number of downlink and uplink subframes may be configured according to different communications schemes. For example, an uplink-to-downlink ratio of a type 3 frame

may be dynamically configured via a common control channel (such as a common physical downlink control channel (CPDCCH)).

In some cases, a control channel may be transmitted using resources that would otherwise be used for data transmission (i.e., a physical downlink control channel (PDSCH)). These control channels may be known as enhanced physical downlink control channels (PDCCHs) or ePDCCHs. Each ePDCCH set may have 2, 4, or 8 resource block (RB) pairs. An ePDCCH may be scheduled using enhanced control channel elements (eCCE) and enhanced resource element groups (eREGs). The number of eCCEs used for an ePDCCH may depend on the aggregation level. In some cases, an ePDCCH may be UE specific. That is, ePDCCH may be transmitted exclusively using a UE-specific search space. In some cases, certain downlink control information (DCI) formats may be used to indicate information about a frame, such as a location of data or a demodulation scheme. In some cases, a UE 115 may support ePDCCH if it has a sufficiently fast decoder, as the ePDCCH is decoded at the end of a subframe (because portions of it may fall in each symbol of the subframe), whereas PDCCH may be transmitted using the first few symbols of a subframe.

PDCCH carries DCI in control channel elements (CCEs), which may consist of nine logically contiguous resource element groups (REGs), where each REG contains 4 resource elements (REs). DCI includes information regarding downlink (DL) scheduling assignments, uplink (UL) resource grants, transmission scheme, UL power control, HARQ information, modulation and coding scheme (MCS) and other information. The size and format of the DCI messages can differ depending on the type and amount of information that is carried by the DCI. For example, if spatial multiplexing is supported, the size of the DCI message is large compared to contiguous frequency allocations. Similarly, for a system that employs multiple-input multiple-output (MIMO), the DCI must include additional signaling information. DCI size and format depend on the amount of information as well as factors such as bandwidth, the number of antenna ports, and duplexing mode.

The PUCCH may be mapped to a control channel defined by a code and two consecutive resource blocks. UL control signaling may depend on the presence of timing synchronization for a cell. PUCCH resources for scheduling request (SR) and channel quality information (CQI) reporting may be assigned (and revoked) through radio resource control (RRC) signaling. In some cases, resources for SR may be assigned after acquiring synchronization through a RACH procedure. In other cases, an SR may not be assigned to a UE 115 through the RACH (i.e., synchronized UEs may or may not have a dedicated SR channel). PUCCH resources for SR and CQI may be lost when the UE is no longer synchronized.

HARQ may be a method of ensuring that data is received correctly over a wireless communication link 125. HARQ may include a combination of error detection (such as using a CRC), forward error correction (FEC), and retransmission (such as an automatic repeat request (ARQ)). HARQ may improve throughput at the medium access control (MAC) layer in poor radio conditions (such as signal-to-noise conditions). In Incremental Redundancy HARQ, incorrectly received data may be stored in a buffer and combined with subsequent transmissions to improve the overall likelihood of successfully decoding the data. In some cases, redundancy bits are added to each message prior to transmission. This may be especially useful in poor conditions. In other cases, redundancy bits are not added to each transmission, but are retransmitted after the transmitter of the original

message receives a negative acknowledgment (NACK) indicating a failed attempt to decode the information.

MIMO wireless systems use a transmission scheme between a transmitter (such as a base station 105) and a receiver (such as a UE 115), where both transmitter and receiver are equipped with multiple antennas. Some portions of the wireless communications system 100 may use beamforming. For example, a base station 105 may have an antenna array with a number of rows and columns of antenna ports that the base station 105 may use for beamforming in its communication with a UE 115. Signals may be transmitted multiple times in different directions (such as each transmission may be beamformed differently).

A resource element may include one symbol period and one subcarrier (such as a 15 KHz frequency range). A resource block may contain 12 consecutive subcarriers in the frequency domain and, for a normal cyclic prefix in each OFDM symbol, 7 consecutive OFDM symbols in the time domain (1 slot), or 84 resource elements. The number of bits carried by each resource element may depend on the modulation scheme (the configuration of symbols that may be selected during each symbol period). Thus, the more resource blocks that a UE 115 receives and the higher the modulation scheme, the higher the data rate may be.

Wireless communications system 100 may support the repetition of multiple symbols to increase a device's ability to synchronize and communicate using unlicensed spectrum. For example, a base station 105 may schedule a frame that includes multiple repetitions, in time or frequency, of a control or data signal. After determining that a channel within unlicensed spectrum is clear using a LBT procedure, the base station may broadcast or transmit the frame to one or more devices, such as a UE 115 or MTC device. For instance, the frame may include multiple repetitions of a DRS, and may be broadcast by the base station to enable synchronization with the base station by a UE 115. In other examples, the signal may include repetitions of a CRS, and upon receipt of the CRSs, a UE 115 may identify a start of a TxOP in unlicensed spectrum. Other signals, such as downlink control and shared channels, may be repeated within a frame transmission in a similar manner to ensure receipt by the UE 115. Additionally, the UE 115 may transmit a frame that includes repetitions of a control or data signal when communicating with the base station.

FIG. 2 illustrates an example of a wireless communications system 200 that supports unlicensed spectrum coverage enhancement for industrial IoT. The wireless communications system 200 may be an example of an IoT or industrial IoT network including a base station 105-a and a UE 115-a, which may be examples of the corresponding devices described with reference to FIG. 1. For example, the UE 115-a may be an example of an IoT device, an MTC device, or an AGV. In the wireless communications system 200, coverage enhancement (such as increased coverage and higher SNR for transmissions) may be achieved through a repetition of a number of signals within uplink and downlink transmissions. That is, through the repetition of various signals (such as DRSs, CRSs, physical uplink and downlink control channels, physical uplink and downlink shared channels and the like), an improved SNR may provide coverage for devices within wireless communications system 200, such as UE 115-a.

The base station 105-a and the UE 115-a may communicate with each other using unlicensed spectrum. For example, the base station 105-a or the UE 115-a may perform a CCA or LBT procedure prior to transmitting a frame 205 that includes a number of subframes 210. The

subframes **210** may be configured for downlink communications from the base station **105-a** to the UE **115-a**, or configured for uplink communications from the UE **115-a** to the base station **105-a**. Between the subframes **210** configured for downlink and subframes **210** configured for uplink transmissions, a special subframe may be used, where the special subframe may include a guard period to control switching between downlink and uplink subframes.

In some cases, the frame **205** may be associated with a certain frame structure type (such as frame structure type 3), where a number of downlink and uplink subframes may be configured. For example, an uplink-to-downlink ratio of frame **205** may be dynamically configured, where the UE **115-a** may determine the uplink-to-downlink ratio following the combination of repetitions of PDCCH within frame **205** (such as the base station **105-a** indicating a subframe configuration to the UE **115-a**). Additionally or alternatively, the frame **205** may include semi-statically configured subframes **210**, and the UE **115-a** may be aware of a corresponding uplink-to-downlink ratio based on the semi-static configuration.

The base station **105-a** may use the frame **205** to broadcast or transmit a repetition of a number of downlink signals. That is, data or control signals may be repeated within the frame **205** or within one or more subframes **210**. For example, as a result of the use of unlicensed spectrum, the UE **115-a** may not be immediately aware of signals transmitted by base station **105-a**. The base station **105-a** may thus broadcast a periodic DRS (such as DRS with a periodicity of one DRS subframe every 80 ms or more). However, to increase the SNR associated with a DRS broadcast, the base station **105-a** may transmit repetitions of the DRS over a number of consecutive subframes **210**. As a result, the UE **115-a** may combine DRS over a number of subframes **210** to determine if there is a starting transmission of DRS. In other examples, and as discussed below, a number of different data and control signals may be repeated within the frame **205**, within subframes **210**, within a TxOP that includes the frame **205**, or over multiple TxOPs.

Repetitions of downlink shared channel transmissions may correspond to a repetition of downlink control channels. For example, PDSCH transmissions may be repeated according to PDCCH repetitions as described below, where there may be a one-to-one mapping to the scheduling of PDCCH in each subframe. Similarly, the number of repetitions of the downlink shared channel transmissions may be indicated by N_{rep} according to a DCI format. In such cases, a device may store N_{rep} PDSCH subframes before decoding a repeated PDCCH, where the N_{rep} PDSCH subframes may be followed by scheduled PDCCHs.

Uplink signals from the UE **115-a** also may be repeated. For instance, an uplink shared channel (such as PUSCH) may be repeated, where PUSCH may be repeated N_{rep} times as indicated by a downlink control channel (such as PDCCH), where N_{rep} represents a number of repetitions. In such cases, the scheduling of the PUSCH may satisfy a scheduling constraint (such as an n+4 scheduling constraint). In some examples, the transmission of PUSCH may continue from the first uplink subframe in a next TxOP if the repetition cannot complete in a current TxOP.

Additionally, uplink control signals (such as PUCCH) may be transmitted with repetitions by the UE **115-a**. Some PUCCH transmissions may be associated with certain SNR characteristics, such as a short PUCCH (sPUCCH) transmission associated with a -6 dB SNR for a 1x2 uplink antenna configuration and a payload of 10 bits. Additionally, a scheduled ePUCCH (such as an ePUCCH scheduled by a

resource grant provided by the base station **105-a**) may be associated with a SNR of -6 dB for a 1x2 uplink antenna configuration and a payload of 50 bits. In some cases, the UE **115-a** may use a periodic PUCCH to provide HARQ feedback to the base station **105-a**.

To provide for the transmission of PUCCHs that enable coverage enhancement, a 14 symbol non-scheduled ePUCCH may be used. For example, the non-scheduled ePUCCH may be transmitted within an uplink subframe that immediately follows a special subframe within the frame **205**. The ePUCCH may be triggered by the same mechanism as sPUCCH (such as in every TxOP) and may not be DCI granted, which may reduce the payload of DCI. The ePUCCH within the uplink subframe following the special subframe may extend a number of symbols used for HARQ feedback. Additionally, a grant may indicate a number of repetitions of the scheduled ePUCCH, and the ePUCCH may be repeated in a similar method as repetitions of PUSCH described above.

In some cases, when accessing a network, the UE **115-a** may use random access procedures. For example, the UE **115-a** may use a physical random access channel (PRACH) or enhanced PRACH (ePRACH) to transmit an encoded random access preamble to initiate an access procedure with the base station **105-a**. In some cases, PRACH may be associated with a -14 dB SNR (such as with a 1x4 uplink antenna configuration); however, a repetition of ePRACH (such as two repetitions) may be sent in contiguous uplink subframes, which may be configured by RRC.

FIG. 3 illustrates an example of DRS subframes **300** that support unlicensed spectrum coverage enhancement for industrial IoT. The DRS subframes may represent an example of DRS subframes that are broadcast by a base station **105** and received by a UE **115**. The DRS subframes **300** may be an example of DRS signals across multiple subframes used by a UE **115** to determine synchronization information, identify a system bandwidth, and identify SIB information from a base station **105**.

In some cases, a multiple-subframe DRS may be used to improve medium access for a device, such as a UE **115**. In such cases, an LBT scheme (such as a category 4 LBT scheme including a random back-off with a variable size contention window) may be used by a base station to support transmissions of DRS subframes **300** (such as multiple subframes carrying DRS). That is, a base station **105** may perform an extended CCA procedure, where the extended CCA may allow for the transmission of multiple DRS subframes. Additionally, a priority class may be configured according to a repetition number associated with a number of repetitions of the DRS. In some cases, the priority class may be configured depending on how much a link budget may be increased.

DRS subframes **300** may include a number of subframes **305** transmitted over a bandwidth **310** that carry DRS. For example, a temporally first subframe (such as first subframe **305-a**) includes a DRS, and subsequent subframes (such as second subframe **305-b** and third subframe **305-c**) include repetitions of the DRS. In some cases, the DRS included in the first subframe **305-a** may be used by any devices not configured for coverage enhancement, while coverage enhancement-capable devices may use DRS in second subframe **305-b** and third subframe **305-c**.

Each subframe **305** may include 14 OFDM symbols **315**, where the DRS spans all 14 OFDM symbols **315**, and the additional OFDM symbols **315** (relative to a 12-symbol subframe) may be used for repetitions of additional signals, such as a PSS, and channels, such as a PBCH. In some cases,

synchronization signals may be repeated within each DRS transmission of DRS subframes **300**, which may improve the detection of DRS transmissions. For example, the first subframe **305-a** may include additional repetitions of PSS, referred to as enhanced PSS (ePSS), where ePSS may be included in symbols 12 and 13 of first subframe **305-a**. An enhanced SSS (eSSS) and ePSS also may be scheduled in symbols 2 and 3, respectively. PSS and SSS may be repeated in a multiple DRS subframe scheme to enable fast acquisition of frames broadcast by a base station **105**. As a result, a device may use the repetition of PSS or ePSS within DRS subframes **300** (such as 4 PSS/ePSS symbols in the 0 through *n*th subframe **305** carrying DRS) to determine a starting transmission timing of a DRS broadcast.

The second subframe **305-b** and the third subframe **305-c** may further be used for coverage enhancement of synchronization signals, PBCHs, and eSIBs. For example, the second subframe **305-b** may include a DRS including additional repetitions of ePSS (such as in symbols 3, 6, 12, and 13) and repetitions of eSSS (such as in symbols 2 and 5). Additionally, it should be noted that while three subframes **305** are shown in the DRS subframes **300**, a different number of subframes may be used for the broadcast of a multiple-subframe DRS.

A PDCCH may be used to schedule eSIB information, and a UE **115** may monitor a different location to determine a number of eSIBs transmitted for coverage enhancement. For example, the first subframe **305-a** may include eSIB that may be accessed by non-coverage enhancement capable devices. Then scheduling of eSIBs used for the coverage enhancement mode may begin in the subsequent DRS subframe, including the second subframe **305-b**. The second subframe **305-b** may include an enhanced MTC PDCCH (eMPDCCH) (which may also be referred to as an ePDCCH), where the eMPDCCH at a certain subframe (*n*) may indicate the number of eSIB repetitions (N_{rep}) starting from the following subframe (subframe *n*+1). A receiving device may therefore combine N_{rep} eSIB signals before decoding the received frame. In such cases, the eMPDCCH will indicate to a UE **115** how many repetitions of eSIB there will be in subframes **305** used to achieve a higher SNR, and the UE **115** may therefore identify how many subframes **305** to combine over time before trying to decode eSIB. In some cases, PBCH also may be repeated over *n* DRS subframes to support coverage enhancement.

FIG. 4 illustrates an example of a subframe **400** including repetitions of a CRS that supports unlicensed spectrum coverage enhancement for industrial IoT. Subframe **400** may be an example of a downlink subframe transmitted by a base station **105** to a UE **115** after synchronization and a cell identifier (ID) is obtained, such as using DRS subframes **300** as described with reference to FIG. 3. The subframe **400** may include a number of tones **410** transmitted during multiple symbols **415**. For example, the subframe **400** may include 14 symbols **415** and 12 tones **410**. The subframe **400** may be an example of a subframe that is used for coverage enhancement by enabling a UE **115** to determine the start of a TxOP.

In some examples, the transmission of repeated signals may improve a device's ability for transmission detection. For instance, in unlicensed spectrum a device, such as a UE **115**, may need to identify a start of a TxOP or a subframe transmission. In some wireless communications systems, a single CRS transmission (which may be decoded when a SNR is greater than -6 dB) may be used for transmission detection. Accordingly, the single CRS transmission may be insufficient when detection at a lower SNR is desired, such

as in an industrial IoT scheme. Accordingly, the repetition of CRS across multiple subframes or within the same subframe may enable coverage enhancement within a system.

In a first example, the device may combine repetitions of CRS across multiple symbols **415** within subframe **400**. That is, CRS may be repeated over multiple symbols **415** in the same subframe **400**. As an example, a CRS for antenna ports 0 and 1 (CRS AP 0/1 **420**), may be transmitted during symbols 0, 4, 7, and 11 of subframe **400**. A repetition of the CRS for antenna ports 0/1 (CRS Repetition AP 0/1 **425**) may be transmitted in symbols 2, 3, 12, and 13 of subframe **400**. Additionally, CRS for antenna ports 2 and 3 (CRS AP 2/3 **430**) may occupy symbols 1 and 8 of subframe **400**.

As a result, the transmission detector of the device may combine multiple CRS symbols (such as up to 8 CRS symbols) that enables an amount of gain for coverage enhancement schemes (such as 9 dB gain). In some cases, the use of CRS repeated over multiple symbols **415** within the subframe **400** may reduce the amount of time for a device to detect the beginning of a TxOP or subframe transmission. In another example, the CRS may be combined over multiple subframes (not shown), where a transmission detector at a device combines multiple symbols including CRS across multiple subframes (such as symbols *n*, *n*+4, *n*+7, *n*+11, *n*+14, . . .) to detect a start of a TxOP.

FIG. 5 illustrates an example of a frame configuration **500** that supports unlicensed spectrum coverage enhancement for industrial IoT. The frame configuration **500** may include a frame **505** with a number of subframes **510** configured as downlink, uplink, or special subframes. The frame configuration **500** may be used by a base station **105** to transmit repetitions of a downlink control signals over multiple subframes **510**.

Repetitions of downlink control signals, such as PDCCH, also may be transmitted to provide for coverage enhancement to wireless devices. Some wireless communications systems may be associated with a certain SNR requirement (such as a -6 dB SNR with an aggregation level of 8, with a 4x2 antenna configuration for downlink transmissions and a 1x4 antenna configuration for uplink transmissions). Accordingly, a number of repetitions may be used to achieve a desired SNR for a coverage enhancement scheme (such as -14 dB).

Using the frame configuration **500**, a PDCCH may be repeated, for example, six times to achieve a SNR that enables increased SNR in unlicensed spectrum. In such cases, the PDCCH may start at a certain subframe **510** (such as an i_{SF} -th subframe) after an LBT process has cleared. The i_{SF} -th subframe **510** may provide a fixed starting point to accumulate a number of PDCCHs for decoding purposes. In some cases, frame **505** may have a semi-statically determined uplink-to-downlink ratio of subframes. In some cases, the repetition of the downlink control channel may be within a same TxOP **520** (such as intra-TxOP repetition), where the number of repetitions (N_{rep}) may be less than a number of downlink subframes (N_D).

The repetitions of the downlink control channel may be transmitted in accordance with the equation $i_{SF} \bmod N_D = m * N_{rep}$, where there may not be any cross-TxOP repetition. In some cases, N_{rep} may be chosen such that N_D is divided to avoid gaps in downlink subframes. As illustrated in FIG. 5, N_{rep} may be equal to 2, and a PDCCH **515-a** may be repeated in a next subframe **510**.

Repetitions of the PDCCH **515** may be started in a temporally first subframe or in a later subframe. For example, repetitions of a PDCCH **515-b** may begin at a temporally third subframe **510**, such as when $N_{rep} = 2$, where

a base station **105** may transmit two independent PDCCHs **515** during the TxOP **520**. As a result, a UE **115** may only need to decode the PDCCH **515-a** and the PDCCH **515-b** in their respective subframes **510**, and may refrain from decoding every subframe **510** of frame **505**. In the example of FIG. **5**, a UE **115** may identify two fixed accumulation or starting points for decoding the PDCCHs **515** with a repetition level of 2, and the UE **115** may not need to look at a candidate of $N_{rep}=2$ which occupies a temporally first or second subframe **510**.

FIG. **6** illustrates an example of a frame configuration **600** that supports unlicensed spectrum coverage enhancement for industrial IoT. The frame configuration **600** may include multiple frames **605** that include a number of subframes **610** configured as downlink, uplink, or special subframes. The frame configuration **600** may be used by a base station **105** to transmit repetitions of a downlink control signals over multiple frames **605**.

In some examples, a downlink control channel (such as a PDCCH **615**) may be repeated across multiple TxOPs **620** (such as inter-TxOP repetition), where N_{rep} is greater than N_D . In such cases, the repetitions may begin at a temporally first subframe **610** ($i_{SF}=0$) and extend to a next TxOP **620**. For example, repetitions of the PDCCH **615** may begin during a temporally first subframe **610** during first TxOP **620-a**, and may extend to a second TxOP **620-b**. In this case, N_{rep} may be chosen to be a multiple of N_D so the repetitions cover the downlink subframes in the next TxOP to avoid a gap in downlink subframes. In some examples, a DCI format may include the repetition number (N_{rep}) that may be used to determine the ending point of the repetitions. Accordingly, a device may decode based on the number of repetitions of the downlink control channel.

N_{rep} may be included in PDCCH such that, if a UE **115** can decode using a subframe **610** (such as subframe x) that is less than N_{rep} , the UE **115** may determine that a later number of repetitions may be redundant and may not be a new PDCCH. As a result, the UE **115** may not need to decode any PDCCH candidates starting from subframes $x+1$ through N_{rep} . For example, the UE **115** may monitor for a PDCCH with $N_{rep}=1$ in every subframe, and the UE **115** may refrain from decoding any PDCCH with a number of repetitions from subframes $x+1$ through N_{rep} after successful decoding using a subframe x .

With inter-TxOP repetition as illustrated in FIG. **6**, a repetition window **625** may be used to avoid excessive power consumption at a device (such as when an LBT process fails). The repetition window **625** may start from a starting subframe **610** (i_{SF}) and end with $i_{SF}+T_{rep}$, where T_{rep} is the duration of the repetition window **625**. In some examples, the device may report a decoding failure if there are no downlink shared channel (such as PDSCH) TxOPs within the repetition window **625**. Additionally, the device may not combine any downlink control channels received outside of the repetition window. That is, a subsequent TxOP **620** may occur at a much later time, and by only combining the repetitions of PDCCH **615** received within the repetition window **625** a number of decoding candidates may be limited.

In some cases, a repetition number, N_{rep} , may be included as part of PDCCH repetitions to avoid variance in accumulation end points of different repetition numbers. For instance, a UE **115** may determine to decode repetition number $N_{rep}=2$ or $N_{rep}=4$. The UE **115** may thus attempt to decode at a temporally first, third, and fifth subframe **610** (such as subframe $n=0, 2, 4$) for $N_{rep}=2$, or attempt to decode at a temporally first and fifth subframe **610** (such as sub-

frames $n=0, 4$) for $N_{rep}=4$. In some examples, the UE **115** may be able to decode a repetition after a temporally second subframe ($n=1$), and the UE **115** may determine that the next two subframes belong to the same PDCCH and will not try to use them to decode for $N_{rep}=2$.

FIG. **7** illustrates an example of a frame configuration **700** that supports unlicensed spectrum coverage enhancement for industrial IoT. The frame configuration **700** may include a frame **705** with a number of subframes **710** configured as downlink, uplink, or special subframes. The frame configuration **700** may be used by a base station **105** to transmit repetitions of a downlink control signals, such as eMPDCCH, over multiple subframes **710**.

In some examples, the downlink control signal may be repeated in the frequency domain (such as the repetition of a 6 RB eMPDCCH, where 48 resource blocks provide 8 repetitions of eMPDCCH). In such cases, a corresponding PDSCH may be scheduled in a subsequent subframe **710** ($n+1$). For example, an eMPDCCH **715** (or an ePDCCH) repeated within subframes **710** may schedule repetitions of PDSCH (such as PDSCH **725-a** and PDSCH **725-b**) in subsequent subframes **710**. Additionally or alternatively, the scheduling of PDSCH may be modified or tightened from $n+2$, such as in MTC deployments, to avoid a gap.

The eMPDCCH **715** may include a repetition number for a control signal (such as $N_{rep,pdcch}$) and the repetition number of a scheduled PDSCH (such as $N_{rep,pdsch}$). That is, there may be multiple indications for a repetition level of various signals, where $N_{rep,pdcch}$ may signal a number of eMPDCCH repetition subframes **710** and $N_{rep,pdsch}$ may indicate a number of PDSCH repetition subframes **710**.

In some examples, resources may be allocated for an entire bandwidth, where there may be an eMPDCCH limit to a 6 RB PDSCH, where $N_{rep,pdcch}=1$, in such cases. That is, a repetition over multiple subframe may not be used, such as when an eMPDCCH **715** has enough repetitions in the frequency domain within a subframe **710**. Accordingly, $N_{rep,pdcch}=1$, but repetitions of a scheduled PDSCH may still be used, so $N_{rep,pdsch}$ may thus indicate a number of repetitions of PDSCH.

In some cases, the repetition of the downlink control channel also may be repeated in the time domain. The repetition may start at the i_{SF} -th subframe **710** following the clearance of an LBT process, which may enable a fixed starting point to accumulate eMPDCCHs for decoding. The repetitions may be scheduled based on an intra-TxOP repetition scheme (where $N_{rep}<N_D$), where repetitions of eMPDCCH may be included within TxOP **720**. The repetitions may begin according to $i_{SF} \bmod N_D = m * N_{rep}$, with no cross-TxOP repetition after clearance of the LBT process. In some cases, N_{rep} may divide the number of downlink subframes to decrease a number of gaps among downlink subframes.

FIG. **8** illustrates an example of a frame configuration **800** for unlicensed spectrum coverage enhancement for industrial IoT. The frame configuration **800** may include a frame **805** with a number of subframes **810** configured as downlink, uplink, or special subframes. The frame configuration **800** may be used by a base station **105** to transmit repetitions of downlink data signals, such as PDSCH.

In some cases, downlink shared channels may be repeated as indicated by an eMPDCCH. In such cases, there may be no frequency hopping, and the repetition of PDSCH may start at a subframe **810** after clearing an LBT process. The repetition of the PDSCH in this case may follow decoding of a scheduling eMPDCCH in a current or previous TxOP, such as when eMPDCCH occupies a last downlink subframe

810. For example, eMPDCCH **815** within a first TxOP **820-a** may be used to schedule repetitions of PDSCH (such as PDSCH **825-a** and PDSCH **825-b**) within a second TxOP **820-b**.

The repetition of the PDSCH also may use the transmission window **830**, T_{rep} , where T_{rep} may start at subframe $n+1$ after a last eMPDCCH in subframe n . If there is no PDSCH TxOP after T_{rep} (such as another TxOP **820** that includes a scheduled transmission of PDSCH), a decoding failure may be reported. This technique may avoid power consumption due to LBT failure. That is, a UE **115** may not wait for the multiple repetitions of the PDSCH after the transmission window **830** has expired.

FIG. **9** shows a block diagram **900** of a wireless device **905** that supports unlicensed spectrum coverage enhancement for industrial. The wireless device **905** may be an example of aspects of a UE **115** as described with reference to FIG. **1**. The wireless device **905** may include a receiver **910**, a UE unlicensed spectrum manager **915**, and a transmitter **920**. The wireless device **905** also may include a processor. Each of these components may be in communication with one another (such as via one or more buses).

The receiver **910** may receive information such as packets, user data, or control information associated with various information channels (such as control channels, data channels, and information related to unlicensed spectrum coverage enhancement for industrial IoT, etc.). Information may be passed on to other components of the device. The receiver **910** may be an example of aspects of the transceiver **1235** described with reference to FIG. **12**.

The UE unlicensed spectrum manager **915** may be an example of aspects of the UE unlicensed spectrum manager **1215** described with reference to FIG. **12**. The UE unlicensed spectrum manager **915** may receive a first frame including a first signal and at least one repetition of the first signal in time or in frequency, the first signal including a data signal or a control signal. The UE unlicensed spectrum manager **915** also may communicate with a base station based on the received first frame (or based on information within the first frame). For example, the UE unlicensed spectrum manager may enable a UE **115** to synchronize timing with a base station **105**, and followed by the reception of downlink signals, such as CRS, PDCCH, or PDSCH.

The transmitter **920** may transmit signals generated by other components of the device. In some examples, the transmitter **920** may be collocated with the receiver **910** in a transceiver module. For example, the transmitter **920** may be an example of aspects of the transceiver **1235** described with reference to FIG. **12**. The transmitter **920** may include a single antenna, or it may include a set of antennas.

FIG. **10** shows a block diagram **1000** of a wireless device **1005** that supports unlicensed spectrum coverage enhancement for industrial IoT. The wireless device **1005** may be an example of aspects of a wireless device **905** or a UE **115** as described with reference to FIGS. **1** and **9**. The wireless device **1005** may include a receiver **1010**, a UE unlicensed spectrum manager **1015**, and a transmitter **1020**. The wireless device **1005** also may include a processor. Each of these components may be in communication with one another (such as via one or more buses).

The receiver **1010** may receive information such as packets, user data, or control information associated with various information channels (such as control channels, data channels, and information related to unlicensed spectrum coverage enhancement for industrial IoT, etc.). Information may be passed on to other components of the device. The receiver

1010 may be an example of aspects of the transceiver **1235** described with reference to FIG. **12**.

The UE unlicensed spectrum manager **1015** may be an example of aspects of the UE unlicensed spectrum manager **1215** described with reference to FIG. **12**. The UE unlicensed spectrum manager **1015** also may include a signal manager **1025** and a communications manager **1030**.

The signal manager **1025** may receive a first frame including a first signal and at least one repetition of the first signal in time or in frequency, the first signal including a data signal or a control signal. In some cases, the first frame includes a semi-statically configured uplink-to-downlink ratio. In some examples, the first signal includes a synchronization signal within a DRS subframe of the received first frame, and the at least one repetition of the first signal may include a repetition of the synchronization signal within the DRS subframe. In some cases, the first signal includes an eMPDCCH within a temporally second subframe of the received first frame.

In other examples, the first signal includes a DRS within a temporally first subframe of the received first frame, where the at least one repetition of the first signal includes a repetition of the DRS within one or more subsequent subframes of the received first frame. Additionally or alternatively, the first signal includes a set of cell-specific reference signals CRSs within a temporally first subframe of the received first frame, where the at least one repetition of the first signal includes a repetition of the CRSs over a set of subsequent subframes. The first signal may include a set of CRSs within a subframe of the received first frame, where the at least one repetition of the first signal includes a repetition of the set of CRSs within a set of symbols within the subframe.

In some cases, the first signal includes a PDCCH within a temporally first subframe of the received first frame, where the temporally first subframe is within a first TxOP, and the at least one repetition of the first signal includes a repetition of the PDCCH within a subsequent TxOP. In some cases, the first signal includes an eMPDCCH within a subframe of the received first frame, where the at least one repetition of the first signal includes a frequency domain repetition of the eMPDCCH within a TxOP as the subframe.

The first signal also may include a PDSCH within a first subframe of the received first frame, where the at least one repetition of the first signal includes a repetition of the PDSCH within additional subframes of a TxOP including the first subframe. Alternatively, the first signal includes a PDSCH within a subframe of the received first frame, and where the at least one repetition of the first signal includes a time-domain repetition of the PDSCH within a TxOP including the subframe and a subsequent TxOP. In some examples, the first signal includes a PDCCH within a subframe of the received first frame, and where the at least one repetition of the first signal includes a repetition of the PDCCH within a same TxOP as the subframe.

The communications manager **1030** may communicate with a base station based on the received first frame. For example, the first frame may include data signals scheduled for the UE **115**, and the UE **115** may respond with data or control signals based on received data from a base station. In some cases, the communications manager **1030** may determine a timing synchronization, a system bandwidth, and SIB information associated with a base station based at least in part on the DRS and the repetition of the DRS. The communications manager **1030** also may transmit a second frame including a second signal and at least one repetition of the second signal, the second signal including a PRACH),

where the second signal and the at least one repetition of the second signal are located within contiguous subframes. In some cases, the communicating includes transmitting a second frame including a second signal and at least one repetition of the second signal in time, the second signal including a PUSCH, where the at least one repetition of the second signal is based on the received first signal. Additionally or alternatively, the communicating includes transmitting a second frame including a second signal and at least one repetition of the second signal, the second signal including a PUCCH, where the at least one repetition of the second signal is located within an uplink subframe following a special subframe.

The transmitter **1020** may transmit signals generated by other components of the device. In some examples, the transmitter **1020** may be collocated with a receiver **1010** in a transceiver module. For example, the transmitter **1020** may be an example of aspects of the transceiver **1235** described with reference to FIG. **12**. The transmitter **1020** may include a single antenna, or it may include a set of antennas.

FIG. **11** shows a block diagram **1100** of a UE unlicensed spectrum manager **1115** that supports unlicensed spectrum coverage enhancement for industrial IoT. The UE unlicensed spectrum manager **1115** may be an example of aspects of a UE unlicensed spectrum manager **915**, a UE unlicensed spectrum manager **1015**, or a UE unlicensed spectrum manager **1215** described with reference to FIGS. **9**, **10**, and **12**. The UE unlicensed spectrum manager **1115** may include a signal manager **1120**, a communications manager **1125**, a SIB component **1130**, a transmission detector **1135**, and a decoder **1140**. Each of these modules may communicate, directly or indirectly, with one another (such as via one or more buses).

The signal manager **1120** may receive a first frame including a first signal and at least one repetition of the first signal in time or in frequency, the first signal including a data signal or a control signal. In some cases, the first frame includes a semi-statically configured uplink-to-downlink ratio. In some examples, the first signal includes a synchronization signal within a DRS subframe of the received first frame, and the at least one repetition of the first signal may include a repetition of the synchronization signal within the DRS subframe. In some cases, the first signal includes an eMPDCCH within a temporally second subframe of the received first frame.

In other examples, the first signal includes a DRS within a temporally first subframe of the received first frame, where the at least one repetition of the first signal includes a repetition of the DRS within one or more subsequent subframes of the received first frame. Additionally or alternatively, the first signal includes a set of cell-specific reference signals CRSs within a temporally first subframe of the received first frame, where the at least one repetition of the first signal includes a repetition of the CRSs over a set of subsequent subframes. The first signal may include a set of CRSs within a subframe of the received first frame, where the at least one repetition of the first signal includes a repetition of the set of CRSs within a set of symbols within the subframe.

In some cases, the first signal includes a PDCCH within a temporally first subframe of the received first frame, where the temporally first subframe is within a first TxOP, and the at least one repetition of the first signal includes a repetition of the PDCCH within a subsequent TxOP. In some cases, the first signal includes an eMPDCCH within a subframe of the received first frame, where the at least one repetition of the

first signal includes a frequency domain repetition of the eMPDCCH within a TxOP as the subframe.

The first signal also may include a PDSCH within a first subframe of the received first frame, where the at least one repetition of the first signal includes a repetition of the PDSCH within additional subframes of a TxOP including the first subframe. Alternatively, the first signal includes a PDSCH within a subframe of the received first frame, and where the at least one repetition of the first signal includes a time-domain repetition of the PDSCH within a TxOP including the subframe and a subsequent TxOP. In some examples, the first signal includes a PDCCH within a subframe of the received first frame, and where the at least one repetition of the first signal includes a repetition of the PDCCH within a same TxOP as the subframe.

The communications manager **1125** may communicate with a base station based on the received first frame. In some examples, the communications manager **1125** may determine a timing synchronization, a system bandwidth, and SIB information associated with a base station based on the DRS and the repetition of the DRS. In some cases, the communicating includes transmitting a second frame including a second signal and at least one repetition of the second signal in time, the second signal including a PUSCH, and where the at least one repetition of the second signal is based on the received first signal. In other examples, the communicating includes transmitting a second frame including a second signal and at least one repetition of the second signal, the second signal including a PUCCH, where the at least one repetition of the second signal is located within an uplink subframe following a special subframe. In some cases, the communications manager **1125** may transmit a second frame including a second signal and at least one repetition of the second signal, the second signal including a PRACH, where the PRACH and the at least one repetition of the PRACH are located within contiguous subframes.

The SIB component **1130** may identify a set of SIBs within a subsequent subframe of the received first frame based on the eMPDCCH. Transmission detector **1135** may detect a start of a TxOP based at least on a combination of the set of CRSs in the temporally first subframe and the set of subsequent subframes, or detect a start of a TxOP based on a combination of the CRSs in the subframe. Additionally or alternatively, the SIB component **1130** may identify a starting point of the PDCCH based on the subframe, identify a starting point of the PDCCH based on the temporally first subframe, or identify a starting point of the eMPDCCH based on the subframe.

The decoder **1140** may decode the first frame based on the identified starting point of the PDCCH and an accumulation of the PDCCH within the same TxOP of the subframe, or may decode the first frame based on the starting point of the PDCCH and an accumulation of the PDCCH within the first TxOP and the subsequent TxOP. In some examples, the decoder **1140** may decode the first frame based on the starting point of the eMPDCCH and an accumulation of the eMPDCCH within the TxOP of the subframe, and may decode the PDSCH based on the PDSCH within the first subframe and the repetition of the PDSCH within the additional subframes.

FIG. **12** shows a diagram of a system **1200** including a device **1205** that supports unlicensed spectrum coverage enhancement for industrial IoT. The device **1205** may be an example of or include the components of a wireless device **905**, a wireless device **1005**, or a UE **115** as described above, such as with reference to FIGS. **1**, **9** and **10**. The device **1205** may include components for bi-directional voice and data

communications including components for transmitting and receiving communications, including a UE unlicensed spectrum manager **1215**, a processor **1220**, memory **1225**, software **1230**, a transceiver **1235**, an antenna **1240**, and an I/O controller **1245**. These components may be in electronic communication via one or more busses (such as a bus **1210**). The device **1205** may communicate wirelessly with one or more base stations **105**.

The processor **1220** may include an intelligent hardware device, (such as a general-purpose processor, a digital signal processor (DSP), a central processing unit (CPU), a micro-controller, an application-specific integrated circuit (ASIC), an field-programmable gate array (FPGA), a programmable logic device, a discrete gate or transistor logic component, a discrete hardware component, or any combination thereof). In some cases, the processor **1220** may be configured to operate a memory array using a memory controller. In other cases, a memory controller may be integrated into the processor **1220**. The processor **1220** may be configured to execute computer-readable instructions stored in a memory to perform various functions (such as functions or tasks supporting unlicensed spectrum coverage enhancement for industrial IoT).

The memory **1225** may include random access memory (RAM) and read only memory (ROM). The memory **1225** may store computer-readable, computer-executable software **1230** including instructions that, when executed, cause the processor to perform various functions described herein. In some cases, the memory **1225** may contain, among other things, a basic input/output system (BIOS) which may control basic hardware or software operation such as the interaction with peripheral components or devices.

The software **1230** may include code to implement aspects of the present disclosure, including code to support unlicensed spectrum coverage enhancement for industrial IoT. The software **1230** may be stored in a non-transitory computer-readable medium such as system memory or other memory. In some cases, the software **1230** may not be directly executable by the processor but may cause a computer (such as when compiled and executed) to perform functions described herein.

The transceiver **1235** may communicate bi-directionally, via one or more antennas, wired, or wireless links as described above. For example, the transceiver **1235** may represent a wireless transceiver and may communicate bi-directionally with another wireless transceiver. The transceiver **1235** also may include a modem to modulate the packets and provide the modulated packets to the antennas for transmission, and to demodulate packets received from the antennas.

In some cases, the wireless device may include a single antenna **1240**. However, in some cases the device may have more than one antenna **1240**, which may be capable of concurrently transmitting or receiving multiple wireless transmissions. The I/O controller **1245** may manage input and output signals for device **1205**. The I/O controller **1245** also may manage peripherals not integrated into device **1205**. In some cases, the I/O controller **1245** may represent a physical connection or port to an external peripheral. In some cases, the I/O controller **1245** may utilize an operating system such as iOS®, ANDROID®, MS-DOS®, MS-WINDOWS®, OS/2®, UNIX®, LINUX®, or another known operating system.

FIG. **13** shows a block diagram **1300** of a wireless device **1305** that supports unlicensed spectrum coverage enhancement for industrial IoT. The wireless device **1305** may be an example of aspects of a base station **105** as described with

reference to FIG. **1**. The wireless device **1305** may include a receiver **1310**, a base station unlicensed spectrum manager **1315**, and a transmitter **1320**. The wireless device **1305** also may include a processor. Each of these components may be in communication with one another (such as via one or more busses).

The receiver **1310** may receive information such as packets, user data, or control information associated with various information channels (such as control channels, data channels, and information related to unlicensed spectrum coverage enhancement for industrial IoT, etc.). Information may be passed on to other components of the device. The receiver **1310** may be an example of aspects of the transceiver **1635** described with reference to FIG. **16**.

Base station unlicensed spectrum manager **1315** may be an example of aspects of the base station unlicensed spectrum manager **1615** described with reference to FIG. **16**. The base station unlicensed spectrum manager **1315** may generate a frame including a signal and at least one repetition of the signal in time or in frequency, the signal including a data signal or a control signal, perform an LBT procedure for one or more channels in the unlicensed spectrum, determine that the one or more channels are clear based on the performed LBT procedure, and transmit the frame based on the determination.

The transmitter **1320** may transmit signals generated by other components of the device. In some examples, the transmitter **1320** may be collocated with a receiver **1310** in a transceiver module. For example, the transmitter **1320** may be an example of aspects of the transceiver **1635** described with reference to FIG. **16**. The transmitter **1320** may include a single antenna, or it may include a set of antennas.

FIG. **14** shows a block diagram **1400** of a wireless device **1405** that supports unlicensed spectrum coverage enhancement for industrial IoT. The wireless device **1405** may be an example of aspects of a wireless device **1305** or a base station **105** as described with reference to FIGS. **1** and **13**. The wireless device **1405** may include a receiver **1410**, a base station unlicensed spectrum manager **1415**, and a transmitter **1420**. The wireless device **1405** also may include a processor. Each of these components may be in communication with one another (such as via one or more busses).

The receiver **1410** may receive information such as packets, user data, or control information associated with various information channels (such as control channels, data channels, and information related to unlicensed spectrum coverage enhancement for industrial IoT, etc.). Information may be passed to other components of the device. The receiver **1410** may be an example of aspects of the transceiver **1635** described with reference to FIG. **16**.

The base station unlicensed spectrum manager **1415** may be an example of aspects of the base station unlicensed spectrum manager **1615** described with reference to FIG. **16**. The base station unlicensed spectrum manager **1415** also may include a base station signal manager **1425**, an LBT component **1430**, and a frame transmission component **1435**.

The base station signal manager **1425** may generate a frame including a signal and at least one repetition of the signal in time or in frequency, the signal including a data signal or a control signal. In some cases, the signal may include a synchronization signal within a DRS subframe of the frame, and the at least one repetition of the signal may include a repetition of the synchronization signal within the DRS subframe. In some examples, the signal may include an eMPDCCH within a temporally second subframe of the frame. Additionally or alternatively, the signal may include

a plurality of CRSs within a temporally first subframe of the frame. In such cases, the at least one repetition of the signal includes a repetition of the CRSs over a plurality of subsequent subframes.

In some examples, the signal includes an eMPDCCH within a subframe of the frame, where the at least one repetition of the signal includes a frequency domain repetition of the eMPDCCH within a transmission opportunity as the subframe. In other examples, the signal includes a PDSCH within a first subframe of the frame, where the at least one repetition of the signal includes a repetition of the PDSCH within additional subframes of a transmission opportunity including the first subframe. Additionally or alternatively, the signal may include a PDSCH within a subframe of the frame, where the at least one repetition of the signal includes a time-domain repetition of the PDSCH within a TxOP including the subframe and a subsequent TxOP.

The LBT component **1430** may perform an LBT procedure for one or more channels in the unlicensed spectrum and determine that the one or more channels are clear based on the performed LBT procedure. For example, the LBT procedure may be an example of an extended CCA, which may include a multi-subframe CCA. The frame transmission component **1435** may transmit the frame based on the determination.

The transmitter **1420** may transmit signals generated by other components of the device. In some examples, the transmitter **1420** may be collocated with a receiver **1410** in a transceiver module. For example, the transmitter **1420** may be an example of aspects of the transceiver **1635** described with reference to FIG. **16**. The transmitter **1420** may include a single antenna, or it may include a set of antennas.

FIG. **15** shows a block diagram **1500** of a base station unlicensed spectrum manager **1515** that supports unlicensed spectrum coverage enhancement for industrial IoT. The base station unlicensed spectrum manager **1515** may be an example of aspects of a base station unlicensed spectrum manager **1615** described with reference to FIGS. **13**, **14**, and **16**. The base station unlicensed spectrum manager **1515** may include a base station signal manager **1520**, an LBT component **1525**, and a frame transmission component **1530**. Each of these modules may communicate, directly or indirectly, with one another (such as via one or more buses).

The base station signal manager **1520** may generate a frame including a signal and at least one repetition of the signal in time or in frequency, the signal including a data signal or a control signal. In some cases, the signal may include a synchronization signal within a DRS subframe of the frame, and the at least one repetition of the signal may include a repetition of the synchronization signal within the DRS subframe. In some examples, the signal may include an eMPDCCH within a temporally second subframe of the frame. Additionally or alternatively, the signal may include a plurality of CRSs within a temporally first subframe of the frame. In such cases, the at least one repetition of the signal includes a repetition of the CRSs over a plurality of subsequent subframes.

In some examples, the signal includes an eMPDCCH within a subframe of the frame, where the at least one repetition of the signal includes a frequency domain repetition of the eMPDCCH within a transmission opportunity as the subframe. In other examples, the signal includes a PDSCH within a first subframe of the frame, where the at least one repetition of the signal includes a repetition of the PDSCH within additional subframes of a transmission opportunity including the first subframe. Additionally or

alternatively, the signal may include a PDSCH within a subframe of the frame, where the at least one repetition of the signal includes a time-domain repetition of the PDSCH within a TxOP including the subframe and a subsequent TxOP.

The LBT component **1525** may perform an LBT procedure for one or more channels in the unlicensed spectrum and determine that the one or more channels are clear based on the performed LBT procedure. Frame transmission component **1530** may transmit the frame based on the determination.

FIG. **16** shows a diagram of a system **1600** including a device **1605** that supports unlicensed spectrum coverage enhancement for industrial IoT. The device **1605** may be an example of or include the components of base station **105** as described above, such as with reference to FIG. **1**. The device **1605** may include components for bi-directional voice and data communications including components for transmitting and receiving communications, including a base station unlicensed spectrum manager **1615**, a processor **1620**, memory **1625**, software **1630**, a transceiver **1635**, an antenna **1640**, a network communications manager **1645**, and a base station communications manager **1650**. These components may be in electronic communication via one or more busses (such as a bus **1610**). The device **1605** may communicate wirelessly with one or more UEs **115**.

The processor **1620** may include an intelligent hardware device, (such as a general-purpose processor, a DSP, a CPU, a microcontroller, an ASIC, an FPGA, a programmable logic device, a discrete gate or transistor logic component, a discrete hardware component, or any combination thereof). In some cases, the processor **1620** may be configured to operate a memory array using a memory controller. In some other cases, a memory controller may be integrated into processor **1620**. The processor **1620** may be configured to execute computer-readable instructions stored in a memory to perform various functions (such as functions or tasks supporting unlicensed spectrum coverage enhancement for industrial IoT).

The memory **1625** may include RAM and ROM. The memory **1625** may store computer-readable, computer-executable software **1630** including instructions that, when executed, cause the processor to perform various functions described herein. In some cases, the memory **1625** may contain, among other things, a BIOS which may control basic hardware or software operation such as the interaction with peripheral components or devices.

The software **1630** may include code to implement aspects of the present disclosure, including code to support unlicensed spectrum coverage enhancement for industrial IoT. The software **1630** may be stored in a non-transitory computer-readable medium such as system memory or other memory. In some cases, the software **1630** may not be directly executable by the processor but may cause a computer (such as when compiled and executed) to perform functions described herein.

The transceiver **1635** may communicate bi-directionally, via one or more antennas, wired, or wireless links as described above. For example, the transceiver **1635** may represent a wireless transceiver and may communicate bi-directionally with another wireless transceiver. The transceiver **1635** also may include a modem to modulate the packets and provide the modulated packets to the antennas for transmission, and to demodulate packets received from the antennas.

In some cases, the wireless device may include a single antenna **1640**. However, in some cases the device may have

more than one antenna **1640**, which may be capable of concurrently transmitting or receiving multiple wireless transmissions. The network communications manager **1645** may manage communications with the core network (such as via one or more wired backhaul links). For example, the network communications manager **1645** may manage the transfer of data communications for client devices, such as one or more UEs **115**.

The base station communications manager **1650** may manage communications with other base stations **105**, and may include a controller or scheduler for controlling communications with UEs **115** in cooperation with other base stations **105**. For example, the base station communications manager **1650** may coordinate scheduling for transmissions to UEs **115** for various interference mitigation techniques such as beamforming or joint transmission. In some examples, the base station communications manager **1650** may provide an X2 interface within an LTE/LTE-A wireless communication network technology to provide communication between base stations **105**.

FIG. **17** shows a flowchart illustrating a method **1700** for unlicensed spectrum coverage enhancement for industrial IoT. The operations of the method **1700** may be implemented by a UE **115** or its components as described herein. For example, the operations of the method **1700** may be performed by a UE unlicensed spectrum manager as described with reference to FIGS. **9** through **12**. In some implementations, a UE **115** may execute a set of codes to control the functional elements of the device to perform the functions described below. Additionally or alternatively, the UE **115** may perform aspects the functions described below using special-purpose hardware.

At block **1705** the UE **115** may receive a first frame including a first signal and at least one repetition of the first signal in time or in frequency, the first signal including a data signal or a control signal. The operations of the block **1705** may be performed according to the methods described with reference to FIGS. **1** through **8**. In some implementations, aspects of the operations of the block **1705** may be performed by a signal manager as described with reference to FIGS. **9** through **12**, which may operate in cooperation with a receiver **910** or **1010** as described with reference to FIG. **9** or **10**, or antenna(s) **1240** and transceiver **1235** as described with reference to FIG. **12**.

At block **1710** the UE **115** may communicate with a base station based at least in part on the received first frame. The operations of the block **1710** may be performed according to the methods described with reference to FIGS. **1** through **8**. In some implementations, aspects of the operations of the block **1710** may be performed by a communications manager as described with reference to FIGS. **9** through **12**, which may operate in cooperation with antenna(s) **1240** and transceiver **1235** as described with reference to FIG. **12**.

FIG. **18** shows a flowchart illustrating a method **1800** for unlicensed spectrum coverage enhancement for industrial IoT. The operations of the method **1800** may be implemented by a UE **115** or its components as described herein. For example, the operations of the method **1800** may be performed by a UE unlicensed spectrum manager as described with reference to FIGS. **9** through **12**. In some implementations, a UE **115** may execute a set of codes to control the functional elements of the device to perform the functions described below. Additionally or alternatively, the UE **115** may perform aspects the functions described below using special-purpose hardware.

At block **1805** the UE **115** may receive a first frame including a first signal and at least one repetition of the first

signal in time or in frequency, where the first signal includes a DRS within a temporally first subframe of the received first frame, and where the at least one repetition of the first signal includes a repetition of the DRS within one or more subsequent subframes of the received first frame. The operations of the block **1805** may be performed according to the methods described with reference to FIGS. **1** through **8**. In some implementations, aspects of the operations of the block **1805** may be performed by a signal manager as described with reference to FIGS. **9** through **12**, which may operate in cooperation with a receiver **910** or **1010** as described with reference to FIG. **9** or **10**, or antenna(s) **1240** and transceiver **1235** as described with reference to FIG. **12**.

At block **1810** the UE **115** may determine a timing synchronization, a system bandwidth, and SIB information associated with a base station based on the DRS and the repetition of the DRS. The operations of the block **1810** may be performed according to the methods described with reference to FIGS. **1** through **8**. In some implementations, aspects of the operations of the block **1810** may be performed by a communications manager as described with reference to FIGS. **9** through **12**.

FIG. **19** shows a flowchart illustrating a method **1900** for unlicensed spectrum coverage enhancement for industrial IoT. The operations of the method **1900** may be implemented by a UE **115** or its components as described herein. For example, the operations of the method **1900** may be performed by a UE unlicensed spectrum manager as described with reference to FIGS. **9** through **12**. In some implementations, a UE **115** may execute a set of codes to control the functional elements of the device to perform the functions described below. Additionally or alternatively, the UE **115** may perform aspects the functions described below using special-purpose hardware.

At block **1905** the UE **115** may receive a first frame including a first signal and at least one repetition of the first signal in time or in frequency, the first signal including a set of CRSs within a subframe of the received first frame, and where the at least one repetition of the first signal includes a repetition of the set of CRSs within a set of symbols within the subframe. The operations of the block **1905** may be performed according to the methods described with reference to FIGS. **1** through **8**. In some implementations, aspects of the operations of the block **1905** may be performed by a signal manager as described with reference to FIGS. **9** through **12**, which may operate in cooperation with a receiver **910** or **1010** as described with reference to FIG. **9** or **10**, or antenna(s) **1240** and transceiver **1235** as described with reference to FIG. **12**.

At block **1910** the UE **115** may detect a start of a TxOP based at least in part on a combination of the CRSs in the subframe. The operations of the block **1910** may be performed according to the methods described with reference to FIGS. **1** through **8**. In some implementations, aspects of the operations of the block **1910** may be performed by a transmission detector as described with reference to FIGS. **9** through **12**.

FIG. **20** shows a flowchart illustrating a method **2000** for unlicensed spectrum coverage enhancement for industrial IoT. The operations of the method **2000** may be implemented by a base station **105** or its components as described herein. For example, the operations of the method **2000** may be performed by a base station unlicensed spectrum manager as described with reference to FIGS. **13** through **16**. In some implementations, a base station **105** may execute a set of codes to control the functional elements of the device to perform the functions described below. Additionally or

alternatively, the base station **105** may perform aspects the functions described below using special-purpose hardware.

At block **2005** the base station **105** may generate a frame including a signal and at least one repetition of the signal in time or in frequency, the signal including a data signal or a control signal. The operations of the block **2005** may be performed according to the methods described with reference to FIGS. **1** through **8**. In some implementations, aspects of the operations of the block **2005** may be performed by a base station signal manager as described with reference to FIGS. **13** through **16**.

At block **2010** the base station **105** may perform an LBT procedure for one or more channels in the unlicensed spectrum. The operations of the block **2010** may be performed according to the methods described with reference to FIGS. **1** through **8**. In some implementations, aspects of the operations of the block **2010** may be performed by a LBT component as described with reference to FIGS. **13** through **16**.

At block **2015** the base station **105** may determine that the one or more channels are clear based at least in part on the performed LBT procedure. The operations of the block **2015** may be performed according to the methods described with reference to FIGS. **1** through **8**. In some implementations, aspects of the operations of the block **2015** may be performed by a LBT component as described with reference to FIGS. **13** through **16**.

At block **2020** the base station **105** may transmit the frame based at least in part on the determination. The operations of the block **2020** may be performed according to the methods described with reference to FIGS. **1** through **8**. In some implementations, aspects of the operations of the block **2020** may be performed by a frame transmission component as described with reference to FIGS. **13** through **16**, which may operate in cooperation with a transmitter **1320** or **1420** as described with reference to FIG. **13** or **14**, or antenna(s) **1640** and transceiver **1635** as described with reference to FIG. **16**.

It should be noted that the methods described above describe possible implementations, and that the operations and the steps may be rearranged or otherwise modified and that other implementations are possible. Furthermore, aspects from two or more of the methods may be combined.

As used herein, a phrase referring to “at least one of” a list of items refers to any combination of those items, including single members. As an example, “at least one of: a, b, or c” is intended to cover: a, b, c, a-b, a-c, b-c, and a-b-c. Also, as used herein, the phrase “based on” shall not be construed as a reference to a closed set of conditions. For example, an exemplary step that is described as “based on condition A” may be based on both a condition A and a condition B without departing from the scope of the present disclosure. In other words, as used herein, the phrase “based on” shall be construed in the same manner as the phrase “based at least in part on.”

The various illustrative logics, logical blocks, modules, circuits and algorithm processes described in connection with the implementations disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. The interchangeability of hardware and software has been described generally, in terms of functionality, and illustrated in the various illustrative components, blocks, modules, circuits and processes described above. Whether such functionality is implemented in hardware or software depends upon the particular application and design constraints imposed on the overall system.

The hardware and data processing apparatus used to implement the various illustrative logics, logical blocks, modules and circuits described in connection with the aspects disclosed herein may be implemented or performed with a general purpose single- or multi-chip processor, a digital signal processor (DSP), an ASIC, a FPGA or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, or, any conventional processor, controller, microcontroller, or state machine. A processor also may be implemented as a combination of computing devices, such as a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration. In some implementations, particular processes and methods may be performed by circuitry that is specific to a given function.

In one or more aspects, the functions described may be implemented in hardware, digital electronic circuitry, computer software, firmware, including the structures disclosed in this specification and their structural equivalents thereof, or in any combination thereof. Implementations of the subject matter described in this specification also can be implemented as one or more computer programs, i.e., one or more modules of computer program instructions, encoded on a computer storage media for execution by, or to control the operation of, data processing apparatus.

If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. The processes of a method or algorithm disclosed herein may be implemented in a processor-executable software module which may reside on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that can be enabled to transfer a computer program from one place to another. A storage media may be any available media that may be accessed by a computer. By way of example, and not limitation, such computer-readable media may include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that may be used to store desired program code in the form of instructions or data structures and that may be accessed by a computer. Also, any connection can be properly termed a computer-readable medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media. Additionally, the operations of a method or algorithm may reside as one or any combination or set of codes and instructions on a machine readable medium and computer-readable medium, which may be incorporated into a computer program product.

Various modifications to the implementations described in this disclosure may be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other implementations without departing from the spirit or scope of this disclosure. Thus, the claims are not intended to be limited to the implementations shown herein, but are to be accorded the widest scope consistent with this disclosure, the principles and the novel features disclosed herein.

Additionally, a person having ordinary skill in the art will readily appreciate, the terms “upper” and “lower” are sometimes used for ease of describing the figures, and indicate

relative positions corresponding to the orientation of the figure on a properly oriented page, and may not reflect the proper orientation of any device as implemented.

Certain features that are described in this specification in the context of separate implementations also can be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation also can be implemented in multiple implementations separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Further, the drawings may schematically depict one more example processes in the form of a flow diagram. However, other operations that are not depicted can be incorporated in the example processes that are schematically illustrated. For example, one or more additional operations can be performed before, after, simultaneously, or between any of the illustrated operations. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products. Additionally, other implementations are within the scope of the following claims. In some cases, the actions recited in the claims can be performed in a different order and still achieve desirable results.

What is claimed is:

1. A method for wireless communication at a device using unlicensed spectrum, comprising:

receiving a first frame including a first signal and at least one repetition of the first signal in time or in frequency, the first signal including a data signal or a control signal, wherein the first signal includes a discovery reference signal (DRS) within a temporally first subframe of the received first frame and an enhanced machine type communication (MTC) physical downlink control channel (eMPDCCH) within a temporally second subframe of the received first frame, and wherein the at least one repetition of the first signal includes a repetition of the DRS within one or more subsequent subframes of the received first frame;

receiving a configuration of the first frame via a common control channel, the configuration comprising a ratio of uplink subframes to downlink subframes, wherein the at least one repetition is based at least in part on the configuration; and

communicating with a base station based at least in part on the received first frame.

2. The method of claim 1, further comprising:

determining a timing synchronization, a system bandwidth, and system information block (SIB) information associated with the base station based at least in part on the DRS and the repetition of the DRS.

3. The method of claim 2, wherein the first signal includes a synchronization signal within a DRS subframe of the

received first frame, and wherein the at least one repetition of the first signal includes a repetition of the synchronization signal within the DRS subframe.

4. The method of claim 2, further comprising:

identifying a plurality of system information blocks (SIBs) within a subsequent subframe of the received first frame based at least in part on the eMPDCCH.

5. The method of claim 1, further comprising:

receiving a second frame including a second signal and at least one repetition of the second signal in time or in frequency, wherein the second signal includes a plurality of cell-specific reference signals (CRSs) within a temporally first subframe of the received second frame, and wherein the at least one repetition of the second signal includes a repetition of the plurality of CRSs over a plurality of subsequent subframes, the method further comprising:

detecting a start of a transmission opportunity based at least on a combination of the plurality of CRSs in the temporally first subframe.

6. The method of claim 1, wherein the at least one repetition of the first signal includes a frequency domain repetition of the eMPDCCH within a same transmission opportunity as the temporally second subframe, the method further comprising:

identifying a starting point of the eMPDCCH based at least in part on the temporally second subframe; and decoding the second frame based at least in part on the starting point of the eMPDCCH and an accumulation of the eMPDCCH within the same transmission opportunity of the temporally second subframe.

7. The method of claim 1, further comprising:

receiving a second frame including a second signal and at least one repetition of the second signal in time or in frequency, wherein the second signal includes a physical downlink control channel (PDCCH) within a subframe of the received second frame, and wherein the at least one repetition of the second signal includes a repetition of the PDCCH within a same transmission opportunity as the subframe, the method further comprising:

identifying a starting point of the PDCCH based at least in part on the subframe; and decoding the second frame based at least in part on the identified starting point of the PDCCH and an accumulation of the PDCCH within the same transmission opportunity as the subframe.

8. The method of claim 1, further comprising:

receiving a second frame including a second signal and at least one repetition of the second signal in time or in frequency, wherein the second signal includes a physical downlink control channel (PDCCH) within a temporally first subframe of the received second frame, and wherein the temporally first subframe is within a first transmission opportunity, and the at least one repetition of the second signal includes a repetition of the PDCCH within a subsequent transmission opportunity, the method further comprising:

identifying a starting point of the PDCCH based at least in part on the temporally first subframe; and decoding the second frame based at least in part on the starting point of the PDCCH and an accumulation of the PDCCH within the first transmission opportunity and the subsequent transmission opportunity.

9. The method of claim 1, further comprising:

receiving a second frame including a second signal and at least one repetition of the second signal in time or in

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- frequency, wherein the second signal includes a physical downlink shared channel (PDSCH) within a first subframe of the received second frame, and wherein the at least one repetition of the second signal includes a repetition of the PDSCH within additional subframes of a transmission opportunity including the first subframe, the method further comprising:
 decoding the PDSCH based at least in part on the PDSCH within the first subframe and the repetition of the PDSCH within the additional subframes.
- 10.** The method of claim **1**, further comprising:
 receiving a second frame including a second signal and at least one repetition of the second signal in time or in frequency, wherein the second signal includes a physical downlink shared channel (PDSCH) within a subframe of the received second frame, and wherein the at least one repetition of the second signal includes a time-domain repetition of the PDSCH within a transmission opportunity including the subframe and a subsequent transmission opportunity.
- 11.** The method of claim **1**, further comprising:
 transmitting a second frame including a second signal and at least one repetition of the second signal, the second signal including a physical random access channel (PRACH), and wherein the second signal and the at least one repetition of the second signal are located within contiguous subframes.
- 12.** A method for wireless communication at a device using unlicensed spectrum, comprising:
 generating a frame including a signal and at least one repetition of the signal in time or in frequency, the signal including a data signal or a control signal, wherein the signal includes a discovery reference signal (DRS) within a temporally first subframe of the frame and an enhanced machine type communication (MTC) physical downlink control channel (eMPDCCH) within a temporally second subframe of the frame, and wherein the at least one repetition of the signal includes a repetition of the DRS within one or more subsequent subframes of the frame;
 performing a listen before talk (LBT) procedure for one or more channels in the unlicensed spectrum;
 determining that the one or more channels are clear based at least in part on the performed LBT procedure;
 transmitting the frame based at least in part on the determination; and
 transmitting, via a common control channel, a configuration of the frame, the configuration comprising a ratio of uplink subframes to downlink subframes within the frame, wherein the at least one repetition is based at least in part on the configuration.
- 13.** The method of claim **12**, wherein the signal includes a synchronization signal within a DRS subframe of the frame, and wherein the at least one repetition of the signal includes a repetition of the synchronization signal within the DRS subframe.
- 14.** The method of claim **12**, further comprising:
 generating a second frame including a second signal and at least one repetition of the second signal in time or in frequency, wherein the second signal includes a plurality of cell-specific reference signals (CRSs) within a temporally first subframe of the second frame, and wherein the at least one repetition of the second signal includes a repetition of the plurality of CRSs over a plurality of subsequent subframes.

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- 15.** The method of claim **12**, further comprising:
 generating a second frame including a second signal and at least one repetition of the second signal in time or in frequency, wherein the at least one repetition of the second signal includes a frequency domain repetition of the eMPDCCH within a same transmission opportunity as the temporally second subframe.
- 16.** The method of claim **12**, further comprising:
 generating a second frame including a second signal and at least one repetition of the second signal in time or in frequency, wherein the second signal includes a physical downlink shared channel (PDSCH) within a first subframe of the second frame, and wherein the at least one repetition of the second signal includes a repetition of the PDSCH within additional subframes of a transmission opportunity including the first subframe.
- 17.** The method of claim **12**, further comprising:
 generating a second frame including a second signal and at least one repetition of the second signal in time or in frequency, wherein the second signal includes a physical downlink shared channel (PDSCH) within a subframe of the second frame, and wherein the at least one repetition of the second signal includes a time-domain repetition of the PDSCH within a transmission opportunity including the subframe and a subsequent transmission opportunity.
- 18.** An apparatus for wireless communication at a device using unlicensed spectrum, in a system comprising:
 a processor;
 memory in electronic communication with the processor; and
 instructions stored in the memory and operable, when executed by the processor, to cause the apparatus to:
 receive a first frame including a first signal and at least one repetition of the first signal in time or in frequency, the first signal including a data signal or a control signal, wherein the first signal includes a discovery reference signal (DRS) within a temporally first subframe of the received first frame and an enhanced machine type communication (MTC) physical downlink control channel (eMPDCCH) within a temporally second subframe of the received first frame, and wherein the at least one repetition of the first signal includes a repetition of the DRS within one or more subsequent subframes of the received first frame;
 receive a configuration of the first frame via a common control channel, the configuration comprising a ratio of uplink subframes to downlink subframes, wherein the at least one repetition is based at least in part on the configuration; and
 communicate with a base station based at least in part on the received first frame.
- 19.** The apparatus of claim **18**, wherein the instructions are further executable to:
 determine a timing synchronization, a system bandwidth, and system information block (SIB) information associated with the base station based at least in part on the DRS and the repetition of the DRS.
- 20.** The apparatus of claim **19**, wherein the first signal includes a synchronization signal within a DRS subframe of the received first frame, and wherein the at least one repetition of the first signal includes a repetition of the synchronization signal within the DRS subframe.

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21. The apparatus of claim 19, wherein the instructions are further executable to:

identify a plurality of SIBs within a subsequent subframe of the received first frame based at least in part on the eMPDCCH.

22. The apparatus of claim 18, wherein the at least one repetition of the first signal includes a frequency domain repetition of the eMPDCCH within a same transmission opportunity as the temporally second subframe, the instructions further executable to:

identify a starting point of the eMPDCCH based at least in part on the subframe; and

decode the first frame based at least in part on the starting point of the eMPDCCH and an accumulation of the eMPDCCH within the same transmission opportunity of the temporally second subframe.

23. The apparatus of claim 18, wherein the instructions are further executable to:

receive a second frame including a second signal and at least one repetition of the second signal in time or in frequency, wherein the second signal includes a physical downlink shared channel (PDSCH) within a subframe of the received second frame, and wherein the at least one repetition of the second signal includes a time-domain repetition of the PDSCH within a transmission opportunity including the subframe and a subsequent transmission opportunity.

24. An apparatus for wireless communication at a device using unlicensed spectrum, in a system comprising:

a processor;

memory in electronic communication with the processor; and

instructions stored in the memory and operable, when executed by the processor, to cause the apparatus to:

generate a frame including a signal and at least one repetition of the signal in time or in frequency, the

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signal including a data signal or a control signal, wherein the signal includes a discovery reference signal (DRS) within a temporally first subframe of the frame and an enhanced machine type communication (MTC) physical downlink control channel (eMPDCCH) within a temporally second subframe of the frame, and wherein the at least one repetition of the signal includes a repetition of the DRS within one or more subsequent subframes of the frame;

perform a listen before talk (LBT) procedure for one or more channels in the unlicensed spectrum;

determine that the one or more channels are clear based at least in part on the performed LBT procedure;

transmit the frame based at least in part on the determination; and

transmit, via a common control channel, a configuration of the frame, the configuration comprising a ratio of uplink subframes to downlink subframes within the frame, wherein the at least one repetition is based at least in part on the configuration.

25. The apparatus of claim 24, wherein the at least one repetition of the signal includes a frequency domain repetition of the eMPDCCH within a transmission opportunity as the subframe.

26. The apparatus of claim 24, wherein the instructions are further executable to:

generate a second frame including a second signal and at least one repetition of the second signal in time or in frequency, wherein the second signal includes a physical downlink shared channel (PDSCH) within a subframe of the second frame, and wherein the at least one repetition of the second signal includes a time-domain repetition of the PDSCH within a transmission opportunity including the subframe and a subsequent transmission opportunity.

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